Electrical Engineering

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The Cover: The Royal York Hotel, Toronto, Ontario, Canada, headquarters for the AIEE 1941 summer convention, June 16–20, towers above its surroundings

Photo by J. H. Mackay, Hydro-Electric Power Commission of Ontario

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High Lights

Engineers and National Defense. For the past two months ELECTRICAL ENGINEERING has carried news items on Defense thought to be of especial interest to engineers, and particularly to electrical engineers. In this issue may be found a third group of current items on this subject (*pages 302–05*). Among these, especial attention is called to one which outlines the efforts being made to keep engineers out of routine military service and retain them where their training and experience will enable them to make their greatest contribution to the National Defense program as a whole (*pages 302–03*). This subject, which is of such great import at this time of accelerated industrial production, is discussed further in: (1) an article advocating a system of "priorities in men" parallel to the system of priorities in materials (*pages 247–50*); (2) President R. W. Sorensen's current message to the AIEE membership (*page 280*); and (3) a "Letter to the Editor" (*page 309*).

Fluorescent Lighting. Introduced commercially only a few years ago, fluorescent lighting already has advanced to a prominent position in the lighting art. Although many of the earlier applications of this new lighting tool were crude and therefore somewhat unsatisfactory, correct methods of application are being developed, with greatly improved installations as a result. These are some of the points brought out at a conference on the subject held during the AIEE 1941 winter convention. Four of the scheduled informal discussions, on low-voltage equipment and installations, are included in this issue (*pages 261–70*); a fifth, outlining progress in high-voltage fluorescent tubing, is scheduled for an early issue.

Bushings. Studies of porcelain oil-filled bushings have resulted in better understanding of the internal and external electrostatic field condition, and in the development of a new method of voltage grading (*Transactions pages 255–60*). Proposed electrical requirements for indoor and outdoor apparatus bushings rated 2,500 volts and higher have been tabulated by the AIEE joint committee on bushings (*Transactions page 266*).

Suppressing Magnetic Vibration. An investigation of the double-frequency vibration of two-pole generators caused by distortion of the stator by magnetic forces resulted in two methods for reducing this vibration: stiffening the stator core, and providing a resilient core-mounting to isolate the vibration (*Transactions pages 283–8*).

Calculating Fault Currents. With industry expanding at its present accelerated rate, a knowledge of fault currents in the electrical systems becomes increasingly important; a method of calculating these fault currents, with an example illustrating in detail how it may be applied, is presented in this issue (*pages 271–9*).

Local Institute Activities. The annual report on AIEE Section and Branch activities for the fiscal year shows organization of two new Sections and three new Student Branches; two former Branches were combined into one when the schools were consolidated. Sections now total 72; Branches 123 (*pages 285–7*).

Construction Theorem. A direct method has been evolved for evaluating operational expressions involving a finite number of different roots; in order that it may be of value to engineers unfamiliar with integration in the complex plane, no mathematically rigorous proof is included (*Transactions pages 273–6*).

Ignitron Arc-Backs. Experiments have been carried out to test the theory that the arc-back rate of ignitrons operating in series should be very low in comparison with the arc-back rate of the individual ignitron operating alone on its share of the voltage; results of the tests are reported (*Transactions pages 292–4*).

Enclosed Bus-Bar Distribution Systems. The enclosed bus-bar type of low-voltage electrical-distribution system for industrial plants, an outgrowth of the mass-production methods of the automotive industry, has met the needs of a variety of public and industrial buildings; its characteristics are discussed (*Transactions pages 297–302*).

Atom Smashing. The principles of atomic structure and atomic transmutation were reviewed, several types of "atom-smashers" described, and some applications of the method of "tracer" atoms to medical problems outlined in an address presented at the AIEE 1941 winter convention (*pages 250–60*).

Transformer Sound Levels. Investigations have shown the basic source of sound in transformers to be the magnetostriction of the magnetic sheet steel; a method of calculating sound levels has been found which gives results in close agreement with measured values (*Transactions pages 277–83*).

High-Potential Testing. An attempt has been made to evaluate the damaging effect on an insulation system of the surge voltages encountered in the rapid production testing of the dielectric strength of low-voltage apparatus (*Transactions pages 289–92*).

Testing by Power Factor. The power-factor method of testing bushing and associated insulation has been used as a maintenance tool in the field and the reconditioning shop; conclusions from eight years' experience are presented (*Transactions pages 308–12*).

Preventive Lightning Protection. Experience with protection against lightning on steel-tower transmission lines operating at from 66 to 220 kv has been analyzed and certain apparent trends reported as a basis for further study (*Transactions pages 249–54*).

Detecting Initial Insulation Failure. A study has been made of the stress at which initial discharge occurs in laboratory specimens of gas-free cable insulation and of the subsequent growth and other changes in the volume of the discharge (*Transactions pages 267–72*).

Electrolytic Scale Removal. Development and operation of electrolytic equipment for use in a continuous pickling line to assist the removal of oxide scale from strip steel are described in this issue (*Transactions pages 294–6*).

Summer-Convention Program. Complete program of the 1941 AIEE summer convention, to be held at Toronto, Canada, June 16–20, appears in this issue (*pages 282–3*); further details on the convention are also presented (*page 281*).

Storage Batteries in Transportation. A review of storage-battery applications in railroad, motor-bus, and aircraft transportation includes discussion of the changes made in battery construction for these services (*Transactions pages 303–07*).

Surges on a 12-Kv System. A theory for the explanation of system overvoltages has been developed on the basis of data observed and recorded for 20 years on the 12-kv system of a large midwestern city (*Transactions pages 260–5*).

Coming Soon. Among special articles and technical papers currently in preparation for early publication are: text of the presidential address by AIEE President R. W. Sorensen (F'19) at the summer convention in Toronto, and of an address at the summer convention on co-operative effort to insure the survival of the free-enterprise system by Howard Coonley; an article on high-voltage fluorescent tubing by J. A. McDermott (A'35); an article on fires of electrical origin in manufacturing plants by G. S. Lawler (M'13); a paper discussing the factors influencing the mechanical strength of cellulose insulation by F. M. Clark (A'24); a paper on atmospheric variations and apparatus flashover by P. H. McAuley (A'36); a paper describing the electrogear, a new electromechanical vehicle drive, by Ernst Weber (F'34); a paper on performance and power supply of large electric-arc furnaces by B. M. Jones (M'24) and C. M. Stearns; a paper dealing with rotor-bar currents in squirrel-cage induction motors by J. S. Gault (M'30); a paper outlining classification and co-ordination of short-time and intermittent ratings and applications by R. E. Hellmund (F'13); and a paper on volt-time areas of impulse sparkover by J. H. Hagenguth (A'28).

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Priorities in Men

HARVEY N. DAVIS

IT MAY BE that an apology is due for my discussing again a topic on which I have had a good deal to say, both privately and publicly, for some months past. My excuse is twofold. First, it seems to me to be an extremely important problem that I am trying to deal with. And second, the crux of it seems to me to be the attitude which the rank and file of the American people is going to take with respect to it.

What an enlightened public opinion understands and demands can and will be done. And on the other hand, what public opinion does not understand, and is likely to misinterpret, cannot be done, no matter how wise those in authority may be, or how clearly they realize the need for doing it. Each one of us has, therefore, an opportunity, and a responsibility, to make clear to the public in every community in which our influence is felt what the nature of this problem is, and what we think should be done about it. Only by constant repetition, on every suitable occasion, can this be done. If, therefore, I repeat some of the things I have said on other occasions, it is because I hope to persuade you to say them elsewhere, over and over again, so as to help both to crystallize and to sustain that public understanding that alone can make wise action possible.

It is widely recognized that a "system of priorities" is necessary to assure proper control and ready availability of the enormous variety of raw materials and complicated military equipment essential to adequate national defense in these dangerous times. However, the parallel and equally vital need for assuring adequate supply and most effective use of the nation's limited supply of specially trained technical manpower seems to be not so widely recognized. Hence, Doctor Davis' strong and thoughtful plea for a system of "priorities in men."

The United States has at last plunged into the most considerable defense program of its history. We have decided to build a two-, if not a three-, ocean navy. We have decided to recruit and train an army sufficient to ensure the future safety and independence not only of ourselves but of any of our neighbors in the Western Hemisphere that may need our help. We have decided to mechanize that army. We have also decided that our own future welfare demands that Hitlerism shall cease to be a potent factor in world affairs. We have set out to prove that the world is no longer the kind of place in which his medieval lust for power can successfully gorge itself on the sufferings of others. We have decided to try to make it clear that this is no longer a world in which such actions can even temporarily pay. In most parts of the world it no longer pays to try to be a private highwayman. I like to think that it no longer pays to try to be an international highwayman, and that it is for the purpose of making this fact clear to all that we are rearming.

Finally, we have decided that the heroic fight that Britain and her allies are putting up is our kind of fight, and that we are going to back that fight with all the munitions of war and all the ships and all the food we can produce for them. For once in my life I find myself in complete accord with the foreign policy of my country. To my mind the only question is: How can we best accomplish what we have set out to do?

Already we are beginning to fear, and in some cases actually to encounter, shortages of certain essential raw materials such as aluminum and nickel. To some extent these current shortages are not real, but are merely reflections of the excitement of these stirring times, of over anxiousness on the part of munitions makers to protect themselves against possible future difficulties. But even so, everyone agrees that the way to meet the situation is to establish a system of priorities which will ensure that the available supplies of these raw materials will go where they will do the most good to the nation.

By the same token we are already facing acute shortages of certain kinds of trained man power, and here there is no question but that the shortages are real and not merely psychological. I suggest that in every such case it is our national duty to conserve to the utmost whatever pool of trained men we already have, and this not merely on a local, but on a nation-wide basis. This means establishing a system of priorities in man power as we have in raw materials.

As a first step toward establishing such a system of priorities in men, we must realize that, at least at present, production is far more important to national defense than is combat training. Modern armies are helpless not only without guns and ammunition, but also without airplanes and tanks and trucks and all the other mechanical equipment of modern warfare. One completely mechanized division nowadays is better than two or three divisions of the old-fashioned sort. And, on the other hand, it takes two or three times as many workers on the industrial front to equip and maintain a mechanized division on the battle front, as it used to take for an old-fashioned division of foot soldiers. A far larger proportion of the total fighting strength of a nation today must be allocated to its factories as compared with its battlefields than was the case in World War I.

Address presented at the AIEE North Eastern District meeting, Rochester, N. Y., April 30–May 2, 1941.

DOCTOR HARVEY N. DAVIS is president of Stevens Institute of Technology, Hoboken, N. J.

This brings me to the crux of the whole matter. What should be your attitude and my attitude and the attitude of the public generally toward the relative priorities of industry and of the draft with respect to trained men? My own belief is that, at least for the present, no trained man who is likely to be useful in production, no matter how young or inexperienced he may be, should be drafted from industry or on his way from college into industry. Whether the situation will be entirely different six months or a year hence, no one can now foresee. As things are now, however, I believe that the needs of the defense industries should be given almost absolute priority over combat training.

In saying this, I am not in the least interested in whether any particular young man wants, in the bottom of his heart, to hide under the bed when war is mentioned, or whether, as is much more likely, he enthusiastically wants to don a uniform and get into the thick of combat training. Unfortunately, there is nothing glamorous about sticking to one's job in the factory when one's friends are marching off behind a band and every man in khaki is a hero. None of these sentiments interest me in the least with respect to the young men I am talking about. What I want is to have every one of them put where he will do our country the most good. At present, in the case of any man who has something vital to contribute to production, I believe that his rightful place is on the industrial front rather than in the Army. Whenever a young man has a kind of training that makes him better fitted than average to take part in defense production, or whenever he is undergoing training of that sort, it is, I think, a matter of duty for his present or prospective employer to ask for his deferment. If the firm for which he is working is not engaged in defense production to such an extent as to seem to justify them in asking for deferments for their production men, then each such man likely to be drafted should be turned loose and helped to place himself where his work will contribute to defense production, and he should not be replaced.

I say this because production men of all levels are already getting very scarce in this country. That this is true of the rank and file of factory operatives is indicated by the statement recently made to me that in one defense industry, six months ago, 50 to 60 per cent of those applying for employment were deemed suitable for training for the kind of work in question, whereas now only 25 to 30 per cent of the run-of-mine applicants can be used. For some time men with skill and experience in the various branches of the machinist's trades have been as scarce as hen's teeth, and expert tool and die makers are simply not to be had. Good foremen are scarce and not easily trained. To find or make supervisors for the next higher levels is a very serious problem in many rapidly expanding defense industries. And so on right up the line to the top. As to the top itself, I have been told that the most serious obstacle that has prevented an even more rapid expansion of aircraft production has been the limitation that nature imposes on the physical and nervous strength and stamina of the top executives who have to do the planning of every extension of plant or augmentation of working force. Under these circumstances I believe that no man skilled in, or in a fair way to soon become skilled in, any phase of production should be permitted to divert his attention to the manual of arms at this crucial moment in our history. As Commissioner Studebaker of the United States Office of Education recently said: "The future of democracy depends on the efficiency of the 'arsenal of democracy'. That efficiency depends on the skill of workers and management."

In applying this general principle to particular cases, the only question seems to be the probable value of each individual to the production program. In the case of engineers, the relationship is unusually direct and obvious. Industrial production has been, for at least 40 years, the especial concern of the engineer. There are far more engineers today actively engaged in planning, directing, and controlling industrial production than there are in the traditional engineer's work of designing the product to be produced, or doing the development work on which that design is based. The typical engineer of today is in general very far from the pure technician that the public commonly thinks he is. He is on the firing line of the industrial front. And that is where the nation most needs to have him.

But there are many others who are playing or will soon have to play important parts in the production program. Among them are men trained in all phases of management. To increase the output of a factory by improving the technique of its management is a far quicker and more effective way of speeding up production than is building a new plant. I venture to assert that if the average level of management in American plants could be brought up to the level of the management of the top tenth, or even the top fourth, of present-day management, to say nothing of the almost certain advances in the art that widespread concentrated attention on this field of work would produce, the resulting effect on production would be very great. And let us not forget that economists, sociologists, and particularly psychologists would have an important part to play in such an industrial revolution, as well as a host of teachers, counselors, and even propagandists, working on and through the administrative personnel of industry.

Whether the establishment of an effective system of priorities in men should be undertaken by means of officially prescribed "reserved occupations", as in England, or as we are trying to do it here now is a serious question.

Undoubtedly local draft boards have ample power under the present selective service law really to select, with the needs of the industrial as well as the combat front always in mind. Recently Brigadier General Lewis B. Hershey, director of selective service, reminded state directors of a provision in the act that it must be administered so that it will not interrupt, delay, or impede the national defense program. "There is," he said, "a dual responsibility imposed upon local boards. They must not only select those who are needed by the armed forces, but must also defer those who are necessary in the production of defense materials. They must take fully into consideration the entire defense picture in making that selection or deferment."

That they shall do just this, is, I believe, the earnest desire and hope of those who have the best interests of the Army itself closest to their professional hearts. Andre Maurois has repeatedly cited as the first of the three or four mistakes that he regards as leading to the fall of France the diversion of too many men from defense production to combat service. One high-ranking Army officer in Washington was quoted to me recently as having told a tale of his own experiences during World War I. He had been put in charge of whipping into shape a regiment of draftees, and, after putting his best into them for some three months, had them just about ready to send abroad. Suddenly some one in Washington discovered that the draft had hamstrung various munitions industries. Thereupon an order went out that all draftees with such and such skills and such and such experience were to be immediately undrafted and sent back to their jobs. As it happened, the order hit this particular regiment particularly hard, for when it had been complied with there was scarcely a corporal's guard left. "And there was I," the officer said, "with three months of enthusiastic work utterly wasted; and there were my men, also with three months wasted, back on the jobs they should have been left at in the first place. I hope the draft boards don't load us up with a lot of men of that same sort again."

Another high-ranking Army man in Washington, whose job is to further the procurement work of the Army, is quoted to me as having recently said, "The trouble is that a lot of these industrial fellows think it is noble and patriotic not to ask for the deferment of any man who hasn't been with them at least six months. Take such and such a company in your area. We've been working on them for three months now, and at last we've pounded some sense into them. They're beginning to ask for the deferments they ought to have been asking for all along."

That's the way the draft situation looks to some of the career men of the Army itself. If any of you are employers of skilled men that ought to be playing a part on the production side of national defense, I hope you will take these two tales to heart, and ask for the deferments that it is your patriotic duty to ask for. And remember that you must state your case clearly and fully and put up a real fight for the deferment of each individual man. Otherwise you won't give a local draft board a leg to stand on in doing what it knows to be wise. It cannot take the initiative; you must.

On the whole our noncentralized method of tackling the priorities in men is working pretty well. I myself have a good deal of faith in the soundness and power of an enlightened public opinion, and in the eagerness and ability of all our constituted authorities, including, in particular, our local draft boards, to act with all the wisdom that their constituencies will permit.

But if we are going to make such a system really work in the still darker days that probably lie ahead, some way must be found to make the decisions of our more than 4,000 local boards more nearly consistent with each other in various parts of the country, in urban and suburban areas, in single industrial areas, and even in different parts of one small city. Merely reporting in summarized statistical form the actions of each board for the benefit of all neighboring boards might help greatly to stem the growing tide of discontent with such inconsistencies as that a second-year student in a certain medical school was deferred by one local board while a third-year student of equal ability in the same school was not deferred by another local board. Such inconsistencies are likely to undermine the morale not only of the general public, but of the draft army itself. Furthermore the young men just about to graduate from our schools of engineering and of business administration want to be able to plan at least a little ahead with at least some assurance as to what this or that local board is going to do. Under our present system these inconsistencies and uncertainties can be minimized only by a vast deal of education of all our draft boards, and even more importantly, of all our citizens as to the serious problems that are involved in this whole matter of priorities in men. Unless this education, which you must help carry on, is effective, we may be forced to adopt by law something much nearer to the British system.

President James Bryant Conant of Harvard University has just returned from a two-months trip to England, and his first published article on the English situation is to be found in a recent issue of the *Harvard Alumni Bulletin*.* In that article he discusses at some length this matter of priorities in men as it is being worked out in a country far more in need of combat man power than we yet are. His report deserves very thoughtful attention, for it may point the way to what we shall soon have to do here, if we are to succeed in helping to preserve democracy in the world by making it work effectively. He says, in part:

> "It is now clearly evident that the British government was far-sighted in developing the idea of 'reserved occupations' before the war. I am not in a position to report on the way the regulations under the act have affected industrial man power, but it is manifest that without these schemes the scientific brain power of the country could not have been properly adjusted to the needs of a modern war.
>
> "The Schedule of Reserved Occupations, first proclaimed in January 1939, by authority of Parliament, listed a thousand or more categories of employment which were then regarded as essential to the defense of the country. Only a dozen or so involved university-trained men, but those dozen were, as events have proved, highly important. They included, for example, architects, university professors and lecturers, school teachers, various types of engineers, scientists, and, of course, medical men, including dentists. Each category was assigned an age limit; men above this age were 'reserved', irrespective of the particular industry in which they were engaged—that is, these men were only permitted to volunteer for a restricted classification of war services. The more vital the occupation was to the national defense, the lower the age at which reservation commenced. For example, doctors were reserved at all ages, physicists at 25, chemists at 21, university teachers at 25, secondary school teachers at 25.
>
> "It is important to note that originally the only consideration involved in drawing up this schedule was the anticipated importance of each category of work to a total war effort. There was no idea that certain types of men should be reserved because they were too valuable for peacetime activities to run the risks of war. To have tried to introduce such an idea into the scheme would have been disastrous both to morale and to the practical applications of the basic concept. At the same time it must be remembered that, since an occupation as such was reserved (above a certain age), a man's

* The British Universities and the War, James Bryant Conant. *Harvard Alumni Bulletin*, April 26, 1941, pages 813–16.

particular job within an occupation was not then taken into account. It must have been recognized at the outset that by the application of such a blanket procedure many occupations would initially be 'overreserved'. This was certainly the case with some types of university-trained men and undoubtedly the case with many skilled and semiskilled trades. But the possibility always existed of (1) subsequently 'de-reserving' an occupation, or (2) raising the age of exemption within a given occupation, or (3) introducing a new principle, namely that the particular job on which a man was engaged must be essential to the national work. Now, after 18 months of war, all these changes have been made.

"The schedule is about to undergo still another revision. In many occupations the age limit is being raised, since experience now shows that, on balance, the needs of the fighting services are more important for the national effort than the particular occupations in question. . . . On the other hand, the age limit on physicists who have proved of the utmost importance to 'war work', has been lowered from 25 to 21. Certain industrial occupations have been removed from the list, and the principle has been now adopted that every man reserved is not merely available for essential work, but is in fact engaged upon it. It should be emphasized, however, that if this last principle had been adopted at the outset, no reservoir of men for new essential work—either scientific or industrial, the result of wartime experience—could have been created.

"The creation of certain reserved occupations involving university men had the effect of bringing into existence a pool of highly trained scientists from which the government could draw as the need arose. To assist the government in this process the Central Register was created. This extremely important agency is now a department of the Ministry of Labor. It has done splendid work and is a vital part of the war effort. At first, registration was voluntary, but last summer the shortage in certain professions was so apparent that the government required physicists, chemists, and engineers to register."

Atom Smashing and Its Applications to Medicine

ROBLEY D. EVANS

A review of the elementary principles of atomic structure and atomic transmutation introduces some typical applications of the method of "tracer" or "spy" atoms to medical problems

INVESTIGATIONS of the structure of atoms have shown that each atom possesses at its center a small, dense, positively charged core, or nucleus. Outside the nucleus the atom consists only of a small swarm of electrons, which are negatively charged and whose number is just sufficient to provide enough negative charge in the atom to balance the positive charge on the nucleus, so that the complete atom is electrically neutral. It is possible to modify the structure of atomic nuclei and thus to produce new atoms having unusual properties. In many cases these artificial atoms are radioactive and can be usefully applied in engineering, physics, chemistry, geology, and medicine.

ATOMS AND NUCLEI

In modern scientific activities only the engineer deals with objects whose dimensions can be readily appreciated by the human mind. Thus the height of a man, the length of a bridge, the weight of a turbine, or the speed of a motor car are all magnitudes that we can appreciate readily through our fundamental senses. This domain lies midway between those with which the astronomer and the nuclear physicist must deal. On the one hand, the astronomer is concerned with distances and masses and times so vast that we cannot appreciate their size, as compared with the experiences of everyday life. At the opposite end of the scale, in the domain of the atomic and nuclear physicists, the dimensions are so minute as to challenge comprehension.

Being small, atoms are also numerous. If we were capable of marking every atom in a glass of water, so that we could recognize that atom if we found it again at a later time, and were then to pour that glass of water into the ocean and allow it to become thoroughly mixed with all the water in all the lakes, rivers, seas, and oceans of the entire world, we would find that every glass of water, regardless of what part of the world samples were taken from, would contain over 5,000 of our original marked atoms.

The glass of water contains about 20 million million million million atoms. Let us imagine that we can enlarge the scale of this glass of water, or contract our own physical dimensions, until we are able to see and examine the individual atoms and their internal structure. If we were to enlarge the scale to make the glass so big that it could contain the entire earth, we would be able to see the individual atoms, each of which would be about 1 inch across. Further examination of these 1-inch atoms would reveal very little, for we would find each of them to consist of a nucleus and a small number of electrons, the dimensions of each of these particles being only a few millionths of an inch. Thus the atom is mainly empty

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space, but it retains its shape and its volumetric displacement by virtue of its very strong internal electric fields.

To be able to see anything in our atom we must again expand the scale. We must make our glass of water so big that the sun could be placed at its center as a tiny pinpoint, and that Mercury, Venus, and the earth could easily traverse their regular orbits about the sun with plenty of room to spare inside the glass. Under those circumstances we could see the individual particles which comprised the atom. If, for example, we chose to examine an atom of oxygen in the water, we would find it to be a roughly spherical object having a diameter of about 10 miles. Occupying this 10-mile spherical space we would find 8 electrons and at the center 1 nucleus, each of these 9 particles being only about the size of a child's toy balloon. Only the very outermost electrons, at the edge of this 10-mile sphere, are involved in ordinary chemical and biochemical reactions. The inner electrons, and especially the atomic nucleus, remain relatively unaware of the chemical or biochemical activity of the outer electrons of the atom.

We may now go to the center of this 10-mile oxygen atom and examine the nucleus. Close inspection would show the nucleus to be a closely packed group of individual particles, like a bunch of large grapes. The oxygen nucleus, if we had maintained its density constant during our expansion of its dimensions, would weigh 500,000 million tons. It would consist of 16 closely packed particles, of two types. There would be 8 particles, called "protons" each having unit positive charge. There would be 8 more particles of substantially the same size and mass as the protons, but having no charge. These neutral particles are called "neutrons." These neutrons and protons are very much alike, and when it is conducive to the formation of a more compact and stable nucleus, neutrons are actually capable of changing themselves into protons, and vice versa. Thus the neutron and proton may be regarded as alternate aspects of one fundamental but unnamed nuclear particle. There appear to be no other particles aside from neutrons and protons in the atomic nucleus; particularly there are definitely no electrons in the nucleus. In the oxygen atom, whose nucleus contains 8 protons and hence shows 8 units of positive charge, there are 8 electrons disposed within the 10-mile sphere that is our atom.

If we examine a large number of oxygen nuclei we shall find a few rare ones which contain 17 particles in the nucleus, and others which contain 18 particles. Like the abundant normal type, each of these nuclei contains 8 protons, hence has a positive charge of 8 units, and hence requires 8 electrons for the formation of a neutral atom. Since the chemical properties are dictated by the number and configuration of the electrons, chemically all these atoms will behave identically. They are therefore called "isotopes"; that is, they have the "same place" in the Mendeléeff periodic table of the chemical elements. These nuclei differ from one another only in the number of neutrons which they contain. Since nearly all of the mass is concentrated in the atomic nucleus, because of the relative lightness of the electrons, these three types of oxygen atoms will have different atomic weights. The "atomic number" of an atom is simply the number of protons in its nucleus, and the "atomic weight" of an atom is given by the total number of neutrons and protons in the nucleus. Thus the atomic weight of ordinary oxygen is 16 while the atomic weights of its two heavier isotopes are 17 and 18.

The simplest atom is that of ordinary hydrogen, whose nucleus consists of a single proton, and which has but 1 atomic electron. The next most complicated atom in nature is that of heavy hydrogen, whose nucleus contains 1 proton and 1 neutron. Again there is but 1 atomic electron, hence the chemical properties are those of hydrogen, although the chemical atomic weight is about twice that of ordinary hydrogen. The next most complicated common atom is that of helium, whose nucleus contains 2 protons and 2 neutrons. The neutral atom of helium therefore contains 2 atomic electrons, and helium has an atomic weight of 4. This helium nucleus of 4 particles, 2 neutrons and 2 protons, is of especially great interest in nuclear physics, as it is a highly stable subunit in heavier nuclei.

All the 278 known stable isotopes of the 92 common chemical elements differ from one another only in the number of neutrons and protons in their nuclei. If two nuclei have the same number of protons, they are called isotopes, and they belong to the same chemical element. If they have the same total number of particles, then they have the same atomic weight and are called "isobars", and in general they will belong to different chemical elements, because the number of protons will be different.

In nuclei the neutrons play the role of a binding cement which holds the entire nucleus together in spite of the very strong electrostatic repulsive forces which the positive protons exert upon one another. Thus in the heavier nuclei we will find a slightly larger proportion of neutrons in the nucleus in order to overcome the rapidly mounting repulsive forces between the larger number of protons. The most complicated nucleus known in nature is the heavy and more common isotope of uranium. This nucleus contains 92 protons; hence uranium has an atomic number of 92 and the neutral uranium atom contains 92 electrons. This nucleus also contains 146 neutrons, making a total of 238 particles in the nucleus; hence the atomic weight is 238. Uranium, like several other heavy elements such as thorium and radium, is not a completely stable nuclear configuration, possibly because of its excessive weight and complexity. It can become more nearly stable by splitting off from itself a helium nucleus, or alpha particle, and expelling this nuclear fragment from the nucleus. This is the origin of the alpha-ray radioactivity of heavy elements, and we shall find that the swiftly moving alpha ray or helium nucleus has found very great usefulness as an atomic bullet.

Figure 1 is a plot which shows each of the known stable nuclei as a square. These nuclei appear to represent all the stable configurations that can be made by taking an arbitrary number of protons, corresponding to particular values of the atomic number, and adding neutrons in such numbers that stable nuclei result. A number of gaps appear in the vertical groups of isotopes in figure 1, from which we can infer that these positions represent unstable

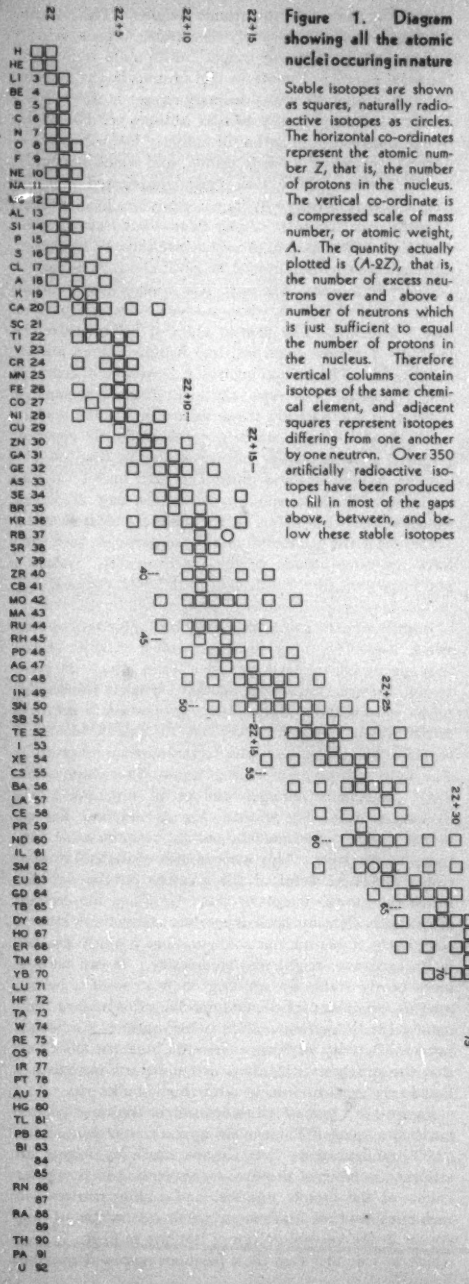


Figure 1. Diagram showing all the atomic nuclei occuring in nature

Stable isotopes are shown as squares, naturally radioactive isotopes as circles. The horizontal co-ordinates represent the atomic number *Z*, that is, the number of protons in the nucleus. The vertical co-ordinate is a compressed scale of mass number, or atomic weight, *A*. The quantity actually plotted is $(A-2Z)$, that is, the number of excess neutrons over and above a number of neutrons which is just sufficient to equal the number of protons in the nucleus. Therefore vertical columns contain isotopes of the same chemical element, and adjacent squares represent isotopes differing from one another by one neutron. Over 350 artificially radioactive isotopes have been produced to fill in most of the gaps above, between, and below these stable isotopes

configurations of neutrons and protons, and that if such nuclei were synthesized in the laboratory, they might have interesting properties. This, in fact, is the case, for all these nuclei are radioactive; that is, they spontaneously transform themselves into a more stable configuration. Transformations of this type are called "artificial radioactivity". The word "artificial" is used only to remind us that the nuclei in question are not found in nature, but have been produced in the laboratory.

TRANSMUTATION

The term "transmutation" originally implied an artificially induced change in the chemical properties of the atom. We see that this means a change in the number of protons in the nucleus. Transmutation is now used in a broader sense to describe any change in the number of protons or neutrons in an atomic nucleus. Thus atom smashing, or transmutation, is not always a smashing but is just as frequently a synthesis in which neutrons or protons are added to an original nucleus.

As an example of a transmutation we may take the relatively simple case of the nuclear reaction which occurs when a nucleus of heavy hydrogen is struck forcefully by another nucleus of heavy hydrogen. Since each nucleus of heavy hydrogen consists of only 1 proton and 1 neutron, we see that the composite nucleus formed when 2 of these heavy hydrogen nuclei or "deuterons" collide has 2 protons and 2 neutrons, as is the case for ordinary helium. In order to bring 2 heavy hydrogen nuclei sufficiently close together so that they may coalesce, one of them must be flung at the other with such enormous velocity as to allow it to overcome the really great electrostatic repulsive forces which these two positive nuclei exert upon one another at atomic distances. Thus when the two nuclei coalesce, the composite nucleus may be in a highly excited state; that is, a great deal of excess energy is present, and hence 1 or more neutrons or protons may be expelled from the group in order to carry away this excess energy. If from the group of 2 neutrons and 2 protons a neutron is expelled, this leaves a nucleus still containing 2 protons, and hence still being an isotope of helium. However, the nucleus only contains 3 particles all together, and hence it has an atomic weight of 3. This artificially produced "light helium" is identical with a known but very rare stable isotope of natural helium.

In the collision between two nuclei

of heavy hydrogen a composite nucleus is formed, a neutron is expelled, and there remains a nucleus of light helium. Thus a transmutation has taken place: 2 atoms of hydrogen have been combined to form 1 atom of helium, and also a free neutron, which escapes from the apparatus. The atomic electrons play no role in these transmutations, but merely follow their atoms around as best they can. In the present case the 2 electrons originally associated with the 2 atoms of hydrogen are needed in the formation of the neutral atom of helium.

The process of atomic transmutation therefore consists of knocking nuclei together in such a way as to change the number of neutrons or protons or both. All the important basic discoveries in nuclear structure and atomic transmutation were obtained by using the alpha particles from radium, and from other heavy radioactive substances, as atomic bullets with which to bombard other nuclei.

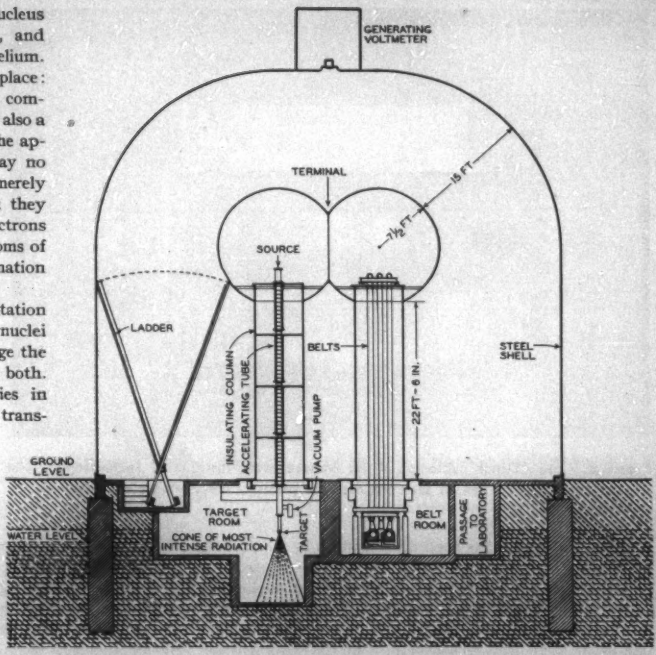


Figure 2. Cross-sectional diagram of the 2,500,000-volt Van de Graaff generator at the Massachusetts Institute of Technology

ATOM SMASHERS

The alpha rays from the natural radioactive substances have very great velocity, some of them moving faster than 2×10^9 centimeters per second, which is 1/15 of the velocity of light and thus would allow them, if unimpeded, to go around the earth in less than two seconds. The energy of any swiftly moving nuclear particle is usually expressed in millions of electron volts. The kinetic energy of the common alpha ray is about 5,000,000 electron volts, which is vastly greater than the kinetic energy obtainable by any known mechanical means. This can be seen by noting that the kinetic energy of each atom in a high-speed rifle bullet is less than 1/10 of an electron volt. Thus the alpha particle has some 50,000,000 times the kinetic energy of the atoms in a rifle bullet.

To smash atoms more abundantly and in a greater variety of ways than is possible with alpha rays alone, it is desirable to put simple atomic nuclei such as those of hydrogen (proton) and heavy hydrogen (deuteron) into high-speed motion. This can be accomplished by producing ionized hydrogen atoms—that is, hydrogen nuclei—in a hydrogen arc, and then accelerating the protons or deuterons thus produced through a discharge tube across which is a potential of several million volts. Electrical devices for artificially accelerating nuclear particles therefore have come to be known as "atom smashers." These atom-smashing machines are often of very great size, and their construction[1,2] and operation involves the advanced principles and practice of electrical engineering.

In the Van de Graaff generator[3] positive electric charge is sprayed, by means of corona points, onto a rapidly moving insulating belt, which carries and delivers this charge to an insulated electrode. This positively charged electrode is then made one of the terminals of a vacuum tube, and protons, deuterons, and other charged particles can be accelerated down this discharge tube and given exit velocities corresponding to several million volts of energy (figure 2). In the Van de Graaff generator the accelerated ions all have substantially the same energy, and this homogeneity, together with the great flexibility and accuracy of its voltage control, makes the electrostatic generator very suitable for detailed fundamental studies of the energetics of nuclear reactions. The maximum voltage obtained by the electrostatic generator is determined by the breakdown potential between the high-voltage terminal and its surroundings. By placing the apparatus in a compressed gas, terminal voltages of between 3,000,000 and 5,000,000 volts have been obtained.

It has been found that larger yields of smashed atoms are obtained as the energy of the bombarding protons, deuterons, or other nuclear particles is increased. To obtain artificially accelerated particles having energies above 10,000,000 electron volts, and hence having a very high atom-smashing efficiency, the cyclotron[4,5,6] is the

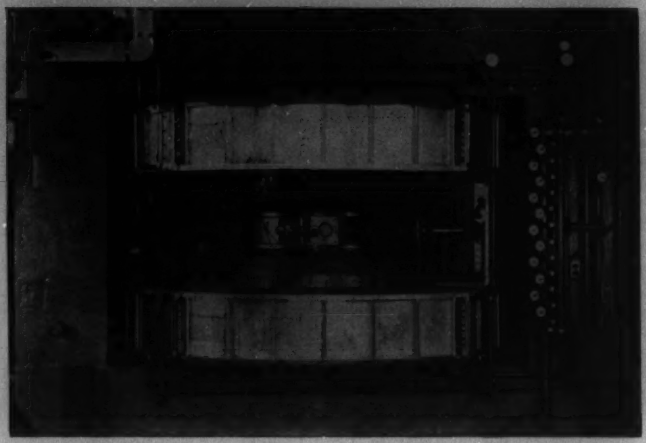


Figure 3. The 42-inch cyclotron at the Massachusetts Institute of Technology. The vacuum chamber can be seen between the poles of the 90-ton electromagnet

best machine which has been developed up to the present time (figure 3). There are now some 15 or 20 cyclotrons of various sizes in operation in the United States, and about twice that number in the entire world. Each of these cyclotrons produces a much larger yield of atomic-transmutation products than could be obtained by the combined use of the alpha rays from all the refined radium in the entire world.

In the cyclotron, protons, deuterons, or other atomic ions are produced at the center of an evacuated chamber, and then are given a succession of 100 or more individual accelerations through a voltage of about 100,000 volts. Each ion therefore emerges from the apparatus with the same kinetic energy which it would have obtained in a single acceleration through a potential difference of some 10,000,000 volts.

Basically, a cyclotron consists of three main components, together with controls. The largest component is an electromagnet for producing a steady magnetic field of the order of 16,000 gausses between two large parallel circular pole pieces. Between these poles is placed a flat circular vacuum chamber containing two hollow D-shaped electrodes. In this evacuated chamber the ions move in a series of semicircular paths between voltage accelerations; hence the name cyclotron, which means "circle tube." The two hollow D-shaped electrodes in the vacuum chamber are connected to the terminals of a radio-frequency oscillator operating in the range between 10 and 15 megacycles, and usually having a power input of the order of 50 kw.

Positive ions produced near the center of the gap between the D electrodes are accelerated toward and into the hollow, negative electrode. There, in the absence of an electrostatic field, they describe a semicircular path due to the side thrust from the magnetic field. Because the angular velocity of any one type of charged particle moving in a magnetic field is independent of the particle's linear velocity or energy, all such semicircles can be traversed by the ion in equal time intervals. After describing a semicircular path inside one of the electrodes, they emerge at its edge, and again enter the gap between the Ds, at a time which is one-half of a radio-frequency cycle later. They are again accelerated across the gap between the electrodes, and enter the opposite D, where they describe a slightly larger semicircular path. Coming once more to the gap between the Ds, the now reversed potential again accelerates them. Thus the ions continue, in resonance with the radio frequency and an appropriate fixed value of the magnetic field, to describe one semicircle during each half-cycle of the radio frequency. After 100 or more cycles their high velocity brings them to semicircular paths whose radius equals the radius of the D-shaped electrodes, and they finally are drawn out of the apparatus by an auxiliary negatively charged deflector plate and allowed to pass out of the vacuum chamber through a thin foil window. Just outside this window, or inside it if preferred, is placed a target containing the chemical element in which transmutations are to be produced.

ARTIFICIAL RADIOACTIVITY

Bombardments of atomic nuclei with protons, deuterons, alpha particles, gamma rays, neutrons, and electrons have produced several hundred successful transmutations, including transmutations of every known stable chemical element. In many of these transmutations the final nucleus produced is identical with one which is already known in nature. However, in more than 350 cases the final nucleus produced is not known in nature, and is therefore artificially radioactive. Artificially radioactive isotopes of every known stable chemical element have been produced and studied.[7]

There are actually five distinct kinds of radioactivity. We have already discussed the case of alpha-ray radioactivity, which is common among the heavy naturally radioactive substances such as uranium, thorium, and radium. Among the artificially radioactive substances, beta-ray radioactivity is most common. This consists of the emission either of negative electrons or of positrons. The fourth type of radioactivity, or spontaneous transmutation, is electron capture, in which the atomic nucleus combines with and destroys one of its atomic electrons. The fifth type is the so-called "isomeric transition," which involves only a shift in the configuration of the

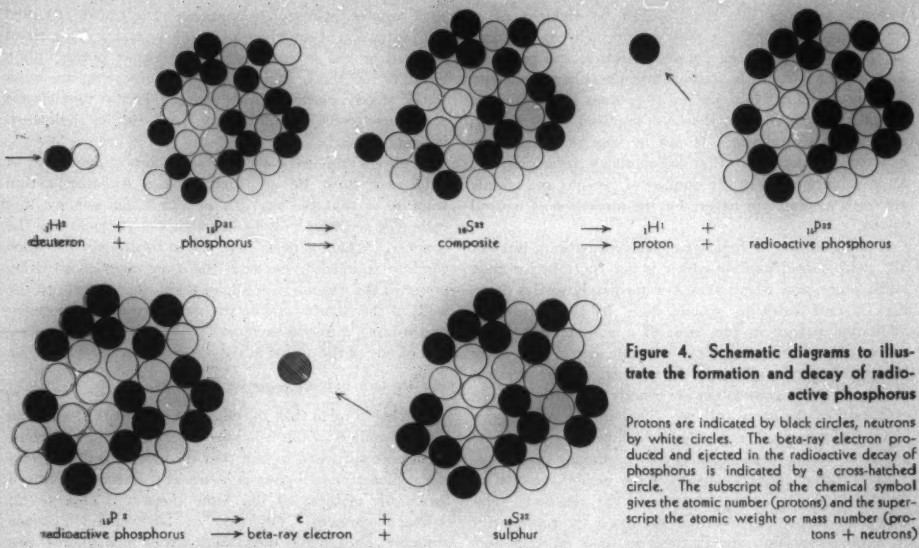

$_1H^2$ + $_{15}P^{31}$ → $_{16}S^{32}$ → $_1H^1$ + $_{15}P^{32}$
deuteron + phosphorus → composite → proton + radioactive phosphorus
$_{15}P^{32}$ → e +
radioactive phosphorus → beta-ray electron + $_{16}S^{32}$
sulphur

Figure 4. Schematic diagrams to illustrate the formation and decay of radioactive phosphorus

Protons are indicated by black circles, neutrons by white circles. The beta-ray electron produced and ejected in the radioactive decay of phosphorus is indicated by a cross-hatched circle. The subscript of the chemical symbol gives the atomic number (protons) and the superscript the atomic weight or mass number (protons + neutrons)

neutrons and protons in the nucleus without any change in the number of either. In the largest number of cases, the artificial radioactivity is of the negative-electron beta-ray-emitting type. We can gain a better understanding of artificial radioactivity by examining the reactions which take place in a particular case; for example, that of the formation and disintegration of radioactive phosphorus.

The element phosphorus has atomic number 15; that is, it has 15 protons in the nucleus, and therefore 15 extranuclear electrons. Phosphorus has but 1 stable isotope occurring in nature. This has an atomic weight of 31; hence the nucleus consists of 15 protons and 16 neutrons. We can make a new and unstable type of phosphorus by adding 1 neutron to the nucleus. This can be realized most efficiently by bombarding ordinary phosphorus with deuterons. The nuclear reaction which takes place is indicated schematically in figure 4. Here we see a deuteron bombarding a phosphorus nucleus, and combining momentarily with it to form an unstable composite. This breaks up almost instantaneously with the emission of a proton, thus leaving the final heavy nucleus with 1 more neutron than is contained in ordinary stable phosphorus. This new product is radioactive phosphorus and has an atomic weight of 32.

On examination of the stable isotopes we find that a stable configuration of 32 particles exists in nature as an isotope of sulphur, which is atomic number 16 and therefore has 16 protons in the nucleus. It is evident that if 1 of the neutrons in the heavy radioactive phosphorus could transform itself into a proton, it could then realize stability, because the new nucleus so formed would be identical with one of the known stable isotopes of ordinary sulphur. This is exactly what happens. One of the neutrons in the nucleus of radioactive phosphorus changes into a proton. The fundamental physical laws of conservation hold among nuclei, and consequently at the same time that 1 unit of positive charge is created in the form of the new proton, 1 unit of negative electrical charge must also be created. Thus there is produced at the boundary of the nucleus a new electron, and this electron is fired away from the nucleus with great velocity because of the excess energy which is released from the nucleus as it becomes more stable in becoming sulphur. This rapidly moving electron is the beta ray.

The time delay between the formation of a radioactive nucleus and its decay depends upon the details of the nuclear configuration, and varies from one radioactive substance to another over extremely wide limits. In the case of radioactive phosphorus 35 out of every million such nuclei undergo the spontaneous transformation to stable sulphur each minute. This is equivalent to saying that half of any given initial stock of such radioactive atoms will remain unaltered for 14 days. The rapidity of decay of any radioactive substance is expressed by the time required for half of any initial stock of such atoms to decay; thus the "half-period" for phosphorus is 14 days.

The beta ray which is shot out from the decaying radioactive nucleus has a velocity very nearly equal to that of light, and in the case of radioactive phosphorus these electrons have kinetic energies up to 1,700,000 electron volts. These electrons are slowed down and eventually stopped by their passage through matter, in which they collide with the atomic electrons of the atoms through which they pass. Following some 50,000 such collisions, in each of which the atom struck is ionized, the beta-ray electron finally comes to rest. Then in the long run of

nature's averages this electron can be thought of as eventually rejoining the sulphur atom which was produced at the moment that the beta-ray electron was produced and expelled from the radioactive phosphorus nucleus. This new sulphur atom, having 16 protons in the nucleus, requires 1 more electron than was required by its parent, radioactive phosphorus. It can be seen that this extra electron is available, so that radioactivity never produces an unbalance between the number of protons and atomic electrons available in nature for the formation of neutral atoms.

A large number of radioactive transformations, but not all, yield a final nucleus which is not quite in its most stable state, and which almost immediately settles down into its most stable or "ground state" by the emission of additional energy in the form of a gamma ray. The energy of these gamma rays is just sufficient to take away the extra energy available in the nucleus, and the physical properties of the gamma ray are exactly the same as those of X rays of the same voltage. That is, the gamma ray is an electromagnetic radiation of high penetrating power which eventually loses its energy by producing ionization. This ionization process consists of the violent removal of an atomic electron from an atom in the absorber. The secondary high-speed electrons produced by gamma-ray or X-ray absorption are identical in their physical and biological properties with the beta-ray electrons from radioactive substances.

DETECTION

Where relatively strong radioactive sources are available, a simple ionization chamber and electrometer, or an electroscope, are satisfactory for observing the integrated ionization produced by a large number of beta rays. Where the highest sensitivity is required, discharge-counters, such as the Geiger-Müller counter, may be used to count the individual beta-ray electrons one by one. These electrical detecting devices are capable of producing an electrical pulse of any desired voltage for each beta-ray electron which passes through the sensitive volume of the counter. Although it has many variations, the discharge tube-counter usually consists of a cylindrical cathode and an axial fine wire anode, sealed into a glass envelope containing dry air or another gas at a pressure of about one tenth of an atmosphere. When a carefully regulated d-c potential is connected across the two electrodes, a voltage can be found where no discharge takes place through the tube until a single free electron enters the volume between the anode and the cathode. Then a momentary electrical discharge takes place between the electrodes, and immediately is quenched. This individual discharge can then be amplified with the aid of vacuum-tube circuits designed especially for this purpose. The output of such an amplifier consists of a series of pulses which are randomly spaced in time, since radioactive disintegration follows the usual statistical laws for a random process. Then one either can record the number of pulses directly on a tape or a message register, or, for higher counting rates, a vacuum-tube scaling circuit can be placed between the output of the amplifier and the message register. Greater convenience of operation, coupled with retention of the highest possible accuracy, is obtained by feeding the series of randomly spaced pulses into a capacity-resistance tank circuit and observing the relatively steady current thus produced in the tank-circuit resistance, which is the operating principle of the counting-rate meter.[8]

Counters designed for the observation of alpha rays or beta rays must be provided with a sufficiently thin window so that the ray can penetrate the window and enter the sensitive volume between the electrodes of the counter. Where gamma rays are to be observed no such window is needed, because the very high penetrating power of the gamma rays allows them to pass through the walls of the counter and to produce, directly in the sensitive volume, a free secondary electron, through the ionization of one of the atoms in the electrodes or the filling gas.

TRACER APPLICATIONS

Bearing in mind that the chemical properties of an atom are determined by the behavior of its outermost electrons, we are not surprised to find that the biochemical behavior of a radioactive substance is identical with the behavior of the stable isotopes of the same element. Thus to all ordinary chemical, physical, or biochemical systems ordinary phosphorus and radioactive phosphorus are indistinguishable, as are ordinary iodine and radioactive iodine, and similarly for all the other elements. Once they have been mixed together, it is impossible to separate by ordinary chemical or biochemical processes the stable from the radioactive atoms of any given element. It may be said that the electrons in any given atom do not know whether their nucleus is radioactive or stable, for this secret is locked in the heart of the nucleus.

We have said earlier that in the process of atom smashing the light and relatively remote atomic electrons have to get along as best they can while the violent collision between two nuclei takes place. It is no surprise that this collision shatters all chemical bonds, and that the new radioactive atom is formed as a free atom, rather than remaining in chemical combination as part of a molecule in the target. These atoms must then be taken by the radioactive chemist or the biologist and synthesized into whatever substances are of interest in the particular study at hand. Thus one cannot produce radioactive hemoglobin by bombarding the red blood cells with deuterons in the hope of making the iron which they contain radioactive. Instead, one must take iron as a target and bombard it with deuterons to produce radioactive iron. From such a bombarded target one atom in every million million may be successfully transmuted into radioactive iron, just as radioactive phosphorus is formed in the case used as an example earlier. This mixture of stable and radioactive iron atoms can then be converted chemically to ferrous sulphate. Then if this ferrous sulphate, containing radioactive iron, is fed to anemic dogs, it will be absorbed, and the new red blood cells which are formed later will contain hemoglobin made with radioactive iron. The utilization of the iron administered in such an experiment can be readily traced in all of its details by observing, with

counters, the radioactivity of samples taken from the blood and various parts of the body. Since the radioactive and normal atoms of iron are inseparable chemically they will retain a constant proportionality to one another during the entire subsequent history of the iron sample. Thus the radioactive atom acts as a tracer which allows one to locate the stable but chemically identical atoms with which it was originally mixed.

The use of tracer isotopes is one of the most widespread modern applications of nuclear physics. The method of radioactive indicators was a natural development from Madame Curie's initial radiochemical work, during the experiments on the discovery and separation of polonium and radium. As early as 1913 Paneth and Hevesy made the first applications of this method to chemical problems. During the years that followed they and their students made extensive investigations of the mechanism of exchange reactions, of oxidation-reduction couples, self-diffusion in lead, the metabolism of plants and animals, and many other problems in chemistry and biology. Thus the groundwork and the fundamental principles of the method of tracer isotopes all were well worked out long before 1930. There were severe limitations on this early work because only the naturally radioactive isotopes were available, so the tracer experiments could only be done on lead (with radium *D*), bismuth (with radium *E*), and thallium (with actinium *C''*).

The use of isotopes as tracers became a major field of applied nuclear physics during the middle and late 1930s. Only then were tracer isotopes of all the chemical elements discovered and made available in quantities, together with the means for detecting them. Now more than 350 radioactive isotopes of all the known stable chemical elements are known.

The present general usefulness of the tracer method therefore finds its origin first in the discovery of artificial radioactivity by the Curie-Joliots in 1934; second, in the perfection of the cyclotron by Lawrence and his collaborators, which provided very strong sources of these new radioactive substances; and third, in the development of detection instruments, based on previous developments in other fields of radioactivity.

Assumptions. In the use of isotopes for indicators it is assumed that the atomic-weight difference between the marked and the ordinary isotopes in any particular element is indistinguishable to the chemical, physical, or biological system being studied. This assumption has been checked many times by measurements of the specific radioactivities, where radioactive tracers are used. Especially pertinent is the determination by Schoenheimer and Rittenberg of the relative abundance of the stable nitrogen isotopes, which is found to be the same in amino acids, proteins, and air. Similarly, Dole has shown that the ratio of the hydrogen isotopes is the same in honey, cholesterol, benzene, and water. Thus the biochemical reactions in which these substances are formed do not distinguish between the isotopes of different atomic weight, even in light elements where the fractional differences in weight are largest.

When radioactive isotopes are used as biological tracers, one must add the condition that all doses be kept sufficiently small so that the presence of beta rays and any other radiations from the radioactivity in the organism will not alter the physiological process being studied. Radiation effects must be studied in separate control experiments and all doses kept well below the measured threshold for physiological effects. This threshold varies considerably. For example, in the study of phospholipid metabolism in mice, a total dose of about 36 microcuries* of phosphorus per mouse may be used if only the brain is to be studied, but this dose will alter the metabolism in other parts of the body. If blood and muscle metabolism are to be studied, only 16 microcuries of phosphorus may be used, while for liver studies only 8 microcuries are allowable. The doses must be even smaller for chromosome work, because 30 per cent of the chromosomes will be broken by a dosage of only 8 microcuries per mouse.

It may be pointed out again that the radioactive tracer atom is perfectly normal until the radioactive transition occurs. Until its disintegration a radioactive isotope is indistinguishable chemically from other isotopes of the same element. For this reason it is sometimes preferable to speak of the method of radioactive "spies", since the words "tracer", "tagged atom", and "marked atom" connote the existence of a difference between the isotopes which is not actually present. The radioactive isotopes are actually used as spies which go around unrecognized in the company of normal atoms of the same chemical type, and at a later time reveal the detailed movements of the normal atoms which they accompany. Ordinary experiments employ one spy atom for each 10^{10} to 10^{15} normal atoms whose course is to be traced.

Limitations. In considering the great merits of the method of isotopic spies or tracers, it is well to bear in mind also the limitations of the method. In the use of radioactive isotopes there are two principal limitations. First, the total amount of radioactivity administered in physiological experiments must be kept below the biological threshold. This imposes a limitation on the initial concentration that can be used, and hence on the maximum dilution that can be detected in any particular experiment. Difficulties from this source are usually not serious and almost always can be avoided by the use of highly sensitive detection apparatus. The second limitation is imposed by the periods of the radioactive isotopes, which are not subject to modification by man. Some elements have radioactive isotopes whose periods are too short to permit any but the simplest and quickest tracer experiments. Thus the radioactive isotopes of nitrogen have half-periods of only 8 seconds and 10 minutes, and these isotopes cannot be used for the study of intermediary metabolism of proteins. Fortunately an alternative isotopic tracer method based on the use of purified individual stable isotopes is available for nitrogen (and also hydrogen, carbon, oxygen, and sulphur). Excellent work on the intermediary metabolism of proteins and fats has been accomplished in this way.[9]

In the past two years great progress has been realized

* A curie of any radioactive element exhibits 3.7×10^{10} disintegrating atoms per second.

in the application of the spy method to problems in metallurgy, chemistry, and biology. Consideration of a few of the applications in biology will give a better understanding of the broad range of problems that can be attacked by this method.

Perhaps the most striking applications of the method of isotopic spies have been in the field of animal, plant, and insect physiology. This is because the method provides for the first time a means of studying the metabolism of various nutrients and toxins while the organism is in a normal, healthy, and equilibrium state.

Plant Metabolism. It has been found that plants are capable of effecting an exchange between the plant root and the very small colloidal clay particles of the kind found in the soil. Studies of this absorption process by a plant have shown for the first time that the nutrient positive ions can and do move in both directions between the roots and the clay particles.[10,11,12] Therefore the nutritional process of contact exchange must be divided into the two oppositely directed processes of contact intake and contact depletion of the root system.

The upward and lateral movement of salts containing potassium, sodium, phosphorus, and bromine has been studied in actively growing and transpiring willow and geranium plants. These experiments have shown conclusively that the path of rapid upward movement of salt is in the wood, or xylem, of the plant, rather than in the bark.[13] In addition to the rapid upward movement through the wood, there is a moderately rapid radial transfer from the wood to the bark.

With the aid of this new tool, plant physiologists are already making rapid progress in the determination of the rates of absorption, paths of movement, and distribution within the plant of nutrient elements.

Animal Metabolism. With the aid of radioactive iron the fate of iron atoms in normal and in anemic animals has been studied exhaustively by Whipple, Hahn, and their colleagues.[14,15] These experiments have disclosed a number of previously unknown facts concerning the metabolism of iron. In normal health the body clings very strongly to the iron which it contains, and absorption and excretion are extremely small. Rapid absorption of iron takes place in an anemic organism; that is, in one in which the need is great. Then the iron is absorbed almost exclusively from the gastrointestinal tract, and is transported by way of the plasma to the blood-producing centers, where it is made entirely into hemoglobin in a very short time. There is no direct exchange of iron between the hemoglobin and the blood plasma. New hemoglobin, containing radioactive iron, is detectable in the blood within about four hours, and the absorbed iron is made entirely into hemoglobin in from four to seven days in anemic dogs. The fractional uptake is found to increase as the size of the dose is diminished. Radioactive red cells readily may be removed from one animal and introduced into another. In this way the breakdown of red blood cells and hemoglobin can be studied quantitatively.

The thyroid gland plays fundamental roles in the regulation of growth and of body heat. Its hormonal secretions are rich in iodine, and the metabolism of this element, which appears to be of basic importance in the proper functioning of the thyroid, is being studied in several laboratories with the aid of radioactive iodine.[16,17,18,19] Both normal and diseased thyroid glands are found to take up iodine from the blood stream within a few minutes after administration. The uptake is very much greater in the case of an enlarged (hyperplastic) gland, while for both normal and hyperplastic thyroid glands the fractional uptake of iodine increases as the size of the dose is diminished. In human beings with toxic goiter, the thyroid gland will take up (figure 5) practically all of the administered iodine if the dose is of the order of 1 milligram or less. Basic studies are in progress on the rate

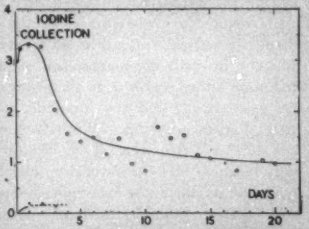


Figure 5. The upper curve shows the average uptake of iodine by the thyroid gland in six cases of human toxic goiter, following the administration of about one milligram of iodine containing radioactive iodine as a tracer. The lower curve shows the very much smaller accumulation in a normal human thyroid

and mechanism of the conversion of the absorbed iodine into the various chemical components of the hormonal secretions of the thyroid gland.

Vitamin B_1 has been synthesized, using radioactive sulphur, and studies of its storage, excretion, and utilization have shown that 10 per cent of the vitamin B_1 in the human body is destroyed every 24 hours.[20]

Using radioactive carbon, Hastings and associates have undertaken the study of carbohydrate metabolism. The formation in the liver of the important animal starch, glycogen, is found to involve a number of biochemical reactions the course of which could not be traced correctly by older methods.

All of these metabolic experiments, taken either individually or collectively, have disclosed extremely general, rapid, and widespread turnover and interchange among the molecules in the living body. Enzymatic equilibrium or steady state reactions occur everywhere all of the time in the body.

In summarizing the tracer work, it should be emphasized that the method of isotopic spies provides a unique method for investigating a normal animal or organism under equilibrium conditions. Calorie balance and nitrogen balance can be maintained rigorously during the entire course of the investigation. That this is a great step forward can be appreciated when it is realized that previous knowledge of intermediary metabolism usually had to come from experiments performed under wholly abnormal conditions. It was necessary to use organisms which were sick or poisoned, or from which certain tissues or

organs had been removed. Abnormal or unnatural compounds had to be administered, or diets unduly enriched or impoverished in the test substances employed. It is small wonder that the results of such experiments were necessarily fragmentary and often incompatible with one another. The entire field of physiology and biochemistry needs to be and is being re-examined with the aid of the powerful method of isotopic spies. In many cases the new results already obtained are contrary to previously accepted viewpoints. These new results serve to clear away much dead wood and to give valid reasons for discarding many alternative or conflicting interpretations of old observations. Fortunately the investigators have usually chosen to examine fundamental problems. Their new results are serving to establish a firm basis on which biochemical and physiological knowledge can be rapidly and consistently enlarged.

RADIATION THERAPY

The tools and the by-products of atom smashing have also provided several new agencies whose efficacy is being tried out in the field of radiation therapy. Fast neutrons were shown several years ago to have profound biological action. The usefulness of intense collimated beams of fast neutrons is being studied by Stone and his colleagues on more than 30 cases of cancer of the head and neck. While a number of cases have been treated, it is too early to draw any conclusions from this work. Fast neutrons penetrate tissue to about the same extent as 300-kv X rays. They produce biological effects which are roughly similar to those of X rays, but show several points of marked contrast. For example, skin reactions produced by fast neutrons both appear and disappear in a considerably shorter time than is the case for equally intense skin effects produced by X rays.

Studies of the therapeutic possibilities of slow neutrons were initiated by Kruger and have been continued by him and other workers. It is well known that both boron and lithium nuclei capture slow neutrons and that the resulting nuclear reaction liberates energetic alpha particles. Efforts are being made to localize molecules containing boron or lithium in tissues which it is desired to radiate. Since the probability for the capture of slow neutrons is much greater in the case of boron and lithium than for the other atoms present in the body, the radiation effects would be confined almost exclusively to the region in which the boron- or lithium-containing molecules had been localized. Difficulties in administering and preventing the diffusion of these materials must be overcome before the method can be used for therapy.

Wherever an artificially radioactive substance can be localized in a tissue which is in need of radiation, really selective interstitial irradiation can be readily administered by the use of the beta rays of very strongly radioactive materials. J. H. Lawrence and his colleagues have shown that phosphorus becomes concentrated in the bone marrow of human beings[21] and in the leukemic tissues in mice.[22] With this and other evidence as a basis, radioactive phosphorus administration has been tried as a possible therapeutic agent in some 75 cases of human

Figure 6. Interior of a new pressure-insulated electrostatic generator[25] at the Massachusetts Institute of Technology, for operation above 1,000,000 volts

leukemia. The results in cases of acute leukemia are not encouraging, but in the chronic leukemias further work seems certainly to be justified. Up to the present the results in many cases appear to be at least as good as those obtained by generalized X radiation of the patient. The administration of radioactive phosphorus can be by mouth, and is certainly much simpler and easier on the patient than the use of whole-body X radiation. Also, if such methods later become well standardized and generally accepted, they could be made readily available to patients in small towns, where expensive X-ray equipment is lacking.

Some of the machines originally designed for nuclear disintegration have been modified so as to be very effective X-ray generators. The Sloan high-frequency resonance transformer has been used for a number of years in two hospitals as a high-intensity X-ray generator[23] operating at about 1,250,000 volts. More recently Trump and Van de Graaff have extended the principles of the Van de Graaff electrostatic generator to produce very compact and efficient super voltage X-ray generators.[24] By the use of high-pressure Freon as an insulating gas, these workers have constructed successfully an X-ray generator which operates continuously at 1,200,000 volts and is completely

contained in a cylindrical tank 2 feet in diameter and 6 feet high. This generator operates at 0.5 milliamperes, and produces an intense radiation of 50 roentgens per minute as a distance of 70 centimeters, with 2 millimeters of lead and 5 millimeters of copper for filtration. A similar generator, to operate above 3,000,000 volts, is now nearing completion. The first 1,000,000-volt X-ray generator of the Van de Graaff type has given excellent hospital service for over 6 years.

These high-voltage generators also may be used for the production of intense and homogeneous beams of cathode rays.[25] These cathode rays have not yet been tested for therapy, but they give every indication of being useful in the radiation of surface malignancies. The depth of penetration of 1,500,000-volt cathode rays is about 8 millimeters in living tissue. Thus the use of cathode rays would permit expenditure of all the radiant energy in a relatively thin layer of surface material. The thickness irradiated can be regulated by adjustment of the cathode-ray voltage. Even with the use of very soft X rays, say 100 kv, so favorable a distribution of energy near the surface cannot be even approximated.

CONCLUSION

Radioactive forms (isotopes) of all of the known stable chemical elements now can be obtained by nuclear transmutation. These artificially radioactive atoms are useful as tracers, or spy atoms, to follow the movement and biological utilization of nutrients and toxins in normal animals and humans, even under equilibrium conditions.

Very strong sources of some artificially radioactive substances eventually may prove useful in radiation therapy. Some atom-smashing machines, when appropriately modified, are useful in metallurgical and clinical radiology.

REFERENCES

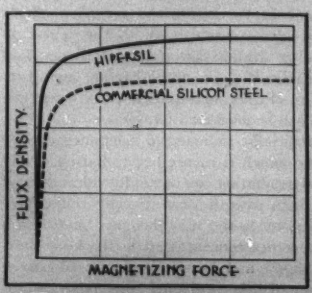
1. W. H. Wells, *Journal of Applied Physics*, volume 9, 1938, pages 677–89.
2. F. N. D. Kurie, *Journal of Applied Physics*, volume 9, 1938, pages 691–701.
3. L. C. Van Atta, D. L. Northrup, C. M. Van Atta, and R. J. Van de Graaff, *Physical Review*, volume 49, 1936, pages 761–76.
4. E. O. Lawrence and M. S. Livingston, *Physical Review*, volume 45, 1934, pages 608–12.
5. E. O. Lawrence and D. Cooksey, *Physical Review*, volume 50, 1936, pages 1131–40.
6. M. S. Livingston, *Review of Scientific Instruments*, volume 7, 1936, pages 55–68.
7. G. T. Seaborg, *Chemical Reviews*, volume 27, 1940, pages 199–285.
8. R. D. Evans and R. L. Alder, *Review of Scientific Instruments*, volume 10, 1939, pages 332–6.
9. R. Schoenheimer and D. Rittenberg, *Physiological Reviews*, volume 20, 1940, pages 218–48.
10. H. Jenny and R. Overstreet, *Proceedings* of National Academy of Sciences, volume 24, 1938, pages 384–92.
11. H. Jenny and R. Overstreet, *Journal of Physical Chemistry*, volume 43, 1939, pages 1185–96.
12. T. C. Broyer and R. Overstreet, *American Journal of Botany*, volume 27, 1940, pages 425–30.
13. P. R. Stout and D. R. Hoagland, *American Journal of Botany*, volume 26, 1939, pages 320–4.
14. P. F. Hahn, J. F. Ross, W. F. Bale, and G. H. Whipple, *Journal of Experimental Medicine*, volume 69, 1939, pages 739–53; volume 70, 1939, pages 443–51; volume 71, 1940, pages 731–6.
15. L. L. Miller and P. F. Hahn, *Journal of Biological Chemistry*, volume 134, 1940, pages 585–90.
16. S. Hertz, A. Roberts, and R. D. Evans, *Proceedings* of Society of Experimental Biology and Medicine, volume 38, 1938, pages 510–13.
17. S. Hertz, A. Roberts, J. H. Means, and R. D. Evans, *American Journal of Physiology*, volume 128, 1940, pages 565–76.
18. J. G. Hamilton and M. H. Soley, *American Journal of Physiology*, volume 127, 1939, pages 557–72.
19. J. G. Hamilton and M. H. Soley, *Proceedings* of the National Academy of Sciences, volume 26, 1940, pages 483–9.
20. H. Borsook, E. R. Buchman, J. B. Hatcher, D. M. Yost, and E. McMillan, *Proceedings* of the National Academy of Sciences, volume 26, 1940, pages 412–18.
21. New International Clinics, J. H. Lawrence, K. G. Scott, and L. W. Tuttle. J. B. Lippincott Company, 1939, pages 33–58.
22. J. H. Lawrence, L. W. Tuttle, K. G. Scott, and C. L. Connor, *Journal of Clinical Investigation*, volume 19, 1940, pages 267–71.
23. R. S. Stone, M. S. Livingston, D. H. Sloan, and M. A. Chaffee, *Radiology*, volume 24, 1935, pages 153–9, 298–302.
24. J. G. Trump, R. J. Van de Graaff, and R. W. Cloud, *American Journal of Roentgenology and Radium Therapy*, volume 44, 1940, pages 610–14.
25. J. G. Trump, R. J. Van de Graaff, and R. W. Cloud, *American Journal of Roentgenology and Radium Therapy*, volume 43, 1940, pages 728–34.

An Improved Magnetic Steel

A NEW silicon steel having a magnetic saturation value approximately one third greater than conventional silicon steel has been announced by the Westinghouse Electric and Manufacturing Company. The new material, which has been named Hipersil (high-permeability silicon steel) reaches this higher saturation at the same magnetizing force as conventional silicon steel; its other characteristics are such that the core losses in transformers in which it is being used are no greater at the increased flux densities than they are in transformers using conventional steels.

The improved properties have been achieved by specially developed rolling procedure and heat treatment which produce in the final product a preferred orientation of the crystal lattice. For that reason, the material must be used in such a way that its "grain" is aligned with the direction of the magnetic field in order to take advantage of its improved properties; if the grain is at right angles to the field, its properties are inferior to those of ordinary silicon steel.

First application of the new material has been in distribution transformers in which size and weight have been reduced by as much as 25 per cent; use of the new material also has facilitated reduction of copper losses and thereby increased short-time overload capacities. Magnetostriction of the new material is reduced so that even at the increased flux density at which the material operates no increase in transformer noise results, as compared with transformers having cores of ordinary silicon steel.



Comparative magnetization curves of conventional silicon steel and Hipersil

Fluorescent Lighting Advances

Discussion at the technical session and conference on fluorescent lighting at the AIEE 1941 winter convention indicated that fluorescent lighting, introduced commercially only a few years ago, is rapidly advancing to a prominent position in the lighting art. Advances in the design and manufacture are resulting in better-quality lamps and equipment in a wider variety of sizes and ratings. Methods of application have been crude and unsatisfactory in many of the early installations, but correct methods are being developed and applied. These factors were among the principal subjects discussed at the session and conference mentioned; essential substance of the scheduled discussions is presented in the following pages. Advances in high-voltage fluorescent tubing and its application also were discussed at this conference. Essential substance of the scheduled discussion on this subject is planned for inclusion in a later issue.

Progress in Lamps and Auxiliaries

O. P. CLEAVER
ASSOCIATE AIEE

IT IS not unusual to hear the present referred to as the "era of fluorescent lighting," an optimistic description in view of the facts, for during 1940 some 600,000,000 large incandescent lamps were sold as compared to almost 9,000,000 fluorescent lamps. Fluorescent lamps, however, have showed phenomenal development in the three years they have been available for practical lighting application, and a growing public demand for them testifies to their satisfactory operation in service.

NEW FLUORESCENT LAMPS

To meet the ever-expanding fields of application for these lamps, new sizes have been introduced during 1940 and the first months of 1941. For convenience they may be divided into two classifications, those for general lighting services, and those for special lighting applications.

New Lamps for General Lighting Service. A 60-inch 100-watt fluorescent lamp (for technical data refer to table I) was announced in the early fall of 1940, making possible about 1$^3/_4$ times more lumens per foot than are obtainable from the 40-watt lamp favored in the past for general lighting. Interest in the 100-watt lamp has been directed toward such applications as industrial lighting in RLM* reflectors, show windows, and continuous "troffer" lighting. Its length has not made it easily adaptable to fixture design and few have appeared as yet for general lighting purposes.

To meet the demand for a shorter lamp that would permit better-proportioned fixtures and still maintain a high lumen output per foot of lamp, the new 65-watt 36-inch fluorescent lamp was introduced in March 1941 (see table I).

Neither of these lamps is as efficient nor has as long life (2,000 hours in each case) as the popular 40-watt 48-inch lamp, yet they offer interesting possibilities for the future. Even though their bulb diameters are larger (*T*-17) than that of the 40-watt lamp (*T*-12), the brightness of the 100-watt and 65-watt lamp is slightly higher, being in the ratio of approximately 1 to 1.13, respectively.

New Lamps for Special Lighting Applications. Fluorescent lighting to date has not been used extensively in the home for many reasons, of which cost and fixture-design problems resulting from the shape and size of the lamp are especially notable. The introduction of the 14-watt 15-inch *T*-12 fluorescent lamp, so designed that it can be operated two in series with a small tungsten incandescent lamp as ballast (in series with the lamps) has resulted in

Figure 1. Standard fluorescent lamps as of March 1, 1941

1—6-watt 9-inch
2—8-watt 12-inch
3—15-watt 18-inch
4—20-watt 24-inch
5—30-watt 36-inch
6—65-watt 36-inch
7—40-watt 48-inch
8—100-watt 60-inch

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*RLM—Reflector Lamp Manufacturers Association.

the introduction of floor lamps with this new fluorescent lamp replacing the customary candle-type filament lamps under the shade. Starting is accomplished manually by delayed switch action. The particular voltage characteristics of this lamp make it the only size that can be so operated.

Another short lamp introduced in 1940 has found some use in homes for bed lamps, decorative table lamps, and picture lighting. This is the small 6-watt 9-inch *T*-5 lamp available in white and daylight only. It has been applied in the commercial field for small display-case lighting, indicator lighting, airplane instrument-board illumination, and on business machines. Very recently, to meet similar applications requiring more light than is available from the 6-watt lamp, an 8-watt 12-inch *T*-5 lamp was made available (table I).

While fluorescent lamps may be many years in arriving at the variety of shapes and sizes now available in incandescent lamps (10,000 estimated), nevertheless in the short span of three years, additions to the original four lengths and two diameters have been sufficient to meet most application requirements. The trend in demand for the various standard lengths during 1940 is as follows:

Length	Watts	Per Cent* of Total
18	15	17
24	20	23
36	30	10
48	40	49
60†	100	1

**Electrical Merchandising*, January 1941.

†Introduced late fall, 1940.

NEW COLORS

The absence of the deep-red wave length in the spectrum of the white and daylight fluorescent lamps, and the presence of a mercury-discharge band spectrum superimposed upon the continuous spectrum obtained from activation of the phosphors, has caused some application difficulties where human skin, meat and vegetable displays, and certain other food displays are involved. Primarily to solve the meat-display problem, a new color has been introduced. Designated as "soft white", it also has proved a solution to many of the other color problems, since it develops a greater proportion of the red radiation than do the standard whites, and subordinates the yellow and green part of the spectrum. Department stores are using it in their women's clothing departments, and beauty parlors, night clubs, restaurants, and residences also are finding it satisfactory. This warmer color, however, is obtained at a lower efficiency—in the 40-watt size, the lumen output is approximately 30 per cent less than for the 3,500-degree white (see table I).

The fluorescent lamp was hailed by the illuminating engineer as a source which would produce colored light at very high efficiencies, thereby opening up many new decorative lighting fields. Statistics indicate, nevertheless, that the colored fluorescent lamps have declined in public demand in relation to the total number of lamps

Table I. Characteristics of the Mazda Fluorescent Lamp

Essential Technical Data

*Watts (Nominal—Lamp Only)	Bulb	Bulb Diameter (Inches)	†Over-All Length (Nominal—Lamp plus 2 Sockets) (Inches)	Base	Lamp Amperes (Approx.)	Lamp Volts (Approx.)	Rated Avg. Life**	Burning Position	*** Approx. Initial Lumens
6	*T*-5	5/8	9	Min. Bipin	0.15	45	750	Any	3500° White 180
									Daylight 155
8	*T*-5	5/8	12	Min. Bipin	0.18	54	750	Any	3500° White 300
									Daylight 250
14	*T*-12	1 1/2	15	Med. Bipin	0.37‡	41‡	1,500	Any	3500° White 460
									Daylight 370
									Soft White 325
15	*T*-8	1	18	Med. Bipin	0.30	56	2,500	Any	3500° White 615
									Daylight 495
									Soft White 435
									Blue 315
									Green 900
									Pink 300
									Gold 375
									Red 45
15	*T*-12	1 1/2	18	Med. Bipin	0.33	48	2,500	Any	3500° White 615
									Daylight 495
									Soft White 435
									Blue 315
									Green 900
									Pink 300
									Gold 375
									Red 45
20	*T*-12	1 1/2	24	Med. Bipin	0.35	62	2,500	Any	3500° White 900
									Daylight 730
									Soft White 640
									Blue 460
									Green 1,300
									Pink 440
									Gold 540
									Red 60
30	*T*-8	1	36	Med. Bipin	0.34	103	2,500	Any	3500° White 1,450
									Daylight 1,200
									Soft White 1,050
									Blue 780
									Green 2,250
									Pink 750
									Gold 930
									Red 120
40	*T*-12	1 1/2	48	Med. Bipin	0.41	108	2,500	Any	3500° White 2,100
									Daylight 1,700
									Soft White 1,500
65	*T*-17	2 1/4	36	Mog. Bipin	1.35	50	2,000	Any	3500° White 2,100
									Daylight 1,800
100	*T*-17	2 1/4	60	Mog. Bipin	1.45	72	2,000	Any	3500° White 4,200
									Daylight 3,350

* For total watts add auxiliary watts.

†This dimension is the distance from the back face of one socket to the back face of the other using sockets of standard thickness. Sockets should be accurately spaced within ±1/32" except ±1/16" may be allowed for the 65- and 100-watt *T*-17 lamps.

‡Values apply when operated on standard 118-volt 15-watt ballast.

**Average life of lamps in burning hours under specified test conditions.

***Approximate lumens when measured at 80 F ambient and under specified test conditions. The light output of a new lamp will appreciably exceed the above published initial values which apply when the lamps have burned 100 hours.

With two 14 watt lamps operated in series with 60-volt 0.5-ampere *S*-11 resistance ballast lamp on 118 volts alternating-current—lamp volts 40, lamp amperes 0.39; on 118 volts direct-current—lamp volts 43, lamp amperes 0.33. (Note that starting difficulty may be encountered on direct-current if line volts fall below 110.)

sold. The trend in color demand during 1940 was as follows:

Color	Per Cent of Total
White	52
Daylight	43
Colors (Red, blue, pink, gold, green)*	5

*"Soft white" was introduced too late for inclusion in this table.

NEW AUXILIARIES

The year was not characterized by any such radical changes in auxiliary design as the separation of the ballast and the switch, which occurred during 1939. However, existing ballasts and switches have been improved by minor design changes and better manufacturing technique.

The acceptance of the two-lamp ballast has been most widespread, accounting for some 80 per cent of the total sales of ballasts today. Longer and more narrow two-lamp ballasts have been designed for the 40-watt and 30-watt lamps to permit their use in wiring channels and in continuous fixtures attached to ceilings and walls. Power-factor-corrected individual ballasts have been provided for all sizes of lamps to take care of applications where only one lamp or an odd number of lamps is required.

The glow type of switch is most universally used at present, but improved thermal types are available, indicating considerable progress in this field during the past year.

Experiments have been undertaken to arrive at a satisfactory solution of the radio-interference problem and at least two manufacturers have provided small inexpensive capacitors which may be attached directly to the fixture across the line. If the fixture is properly grounded, this method proves satisfactory in so far as line-feedback radiation is concerned.

IMPROVEMENTS IN LIFE, EFFICIENCY, AND COST OF LIGHT

Improvements in manufacturing technique and machinery for producing fluorescent lamps are also largely responsible for the remarkable advances made in life and efficiency of these lamps during the three years they have been commercially available. Starting in 1938 with a life span of 1,500 hours, today the standard lamps have life ratings of from 2,000 hours to 2,500 hours, depending on size and wattage (see table I). In that same time, the average efficiency in lumens per watt has increased nearly 40 per cent.

Price reductions also have been frequent, until the average list price today is about 65 per cent of that of two years ago. These price reductions, combined with longer life and higher efficiencies, make it possible to buy for a dollar in 1941 about seven times as many fluorescent "lumen-hours" (white and daylight) as in 1938, as shown in figure 2. Such improvements have greatly extended the fields of economic application for these new light sources, and are responsible in large measure for the steep slope of the ever-rising curve of fluorescent lamp sales.

Reliable estimates of the unit sales of fluorescent lamps expected by lamp manufacturers for 1941 are reported as ranging from 20,000,000 to 25,000,000. Such sales, combined with those of fixtures, ballasts, switches, sockets, wiring, and other equipment, would result in a $250,000,000 industry—that did not even exist three years ago.

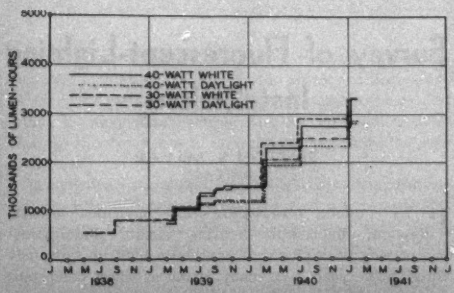

Figure 2. Increase in lumen hours per dollar of lamp list price since 1938. Major factors in the increase are improved efficiency and life of lamps and decrease in prices

Progress in Fluorescent-Lighting Equipment

A. B. ODAY

IN ORDER to get a better picture of the progress that has taken place with fluorescent-lamp equipment, it perhaps would be well to indicate where we started and how far we have gone since the fluorescent lamp first came into being. The fluorescent lamp first was made commercially available about 2¾ years ago. This new source was radically different in shape, size, method of operation, efficiency, brightness, and color quality from anything we ever had had before. We had little or no experience with sources of this type and therefore no precedents were available to help guide us. In 2¾ years the public has placed into operation between 8,000,000 and 10,000,000 of these new lamps. Considering that we started out with very little knowledge as to where, how, or in what quantity these new lamps would be used, I believe that it is not bragging too much to say that the industry has done a remarkable job.

It is of course easy to criticize what has been done and say that the mistakes were obvious and should have been avoided. Many have remarked that some early mistakes could have been eliminated if the introduction of these lamps had been delayed until a complete range of sizes and an adequate supply of well-designed lighting fixtures were available. A satisfactory answer to this criticism might be to remind the critics that lighting evolution has never been carried out on this basis. Most of the lighting

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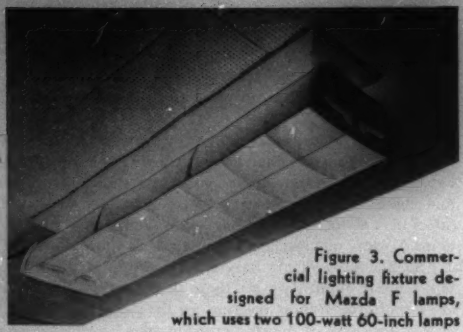

Figure 3. Commercial lighting fixture designed for Mazda F lamps, which uses two 100-watt 60-inch lamps

progress made to date has been built on practical experience. From experience we have found what not to do as well as what to do.

If the factors just mentioned are given due consideration one will agree that much of the early equipment, while inadequate in light of our present knowledge, was in reality about the most logical that could have been developed. In the year 1938, when fluorescent lamps were introduced, about all we had to start with toward a complete fixture, was a lamp, two sockets, an auxiliary, and a piece of wiring channel. The very first equipment was made up from these parts.

Many individuals have been prone to criticize manufacturers of lighting equipment. In my opinion severe criticism should be withheld, since they have developed lighting equipment on a basis that is usually considered logical. Certainly, in order to survey equipment needs to serve these new lamps, it was essential to estimate demands for new lighting equipment of different types, to make up suitable designs, to find money for tools to manufacture new equipment—during the early part of 1938 this in itself was not an easy task. Last but by no means least, time was required to start commercial production. While the permanently established manufacturers of lighting equipment were giving serious consideration to these requirements, many local metal-working plants assembled so-called lighting fixtures and peddled them to customers in their immediate neighborhoods.

All these early difficulties are recounted, not as an excuse for jobs done poorly, but rather as a background for the beginning of what eventually will prove to be a very important epoch in our lighting history.

Today in the early months of 1941 we can point with pride to real progress in the development of fluorescent-lighting equipment. If one considers only the availability of meritorious equipment, there is no excuse at the present time for the existence of poor fluorescent-lighting installations. Practically all the regular established manufacturers of lighting equipment are well prepared to serve the industry and the public.

In considering the progress we have enjoyed so far, mention should be made of the various specifications for fluorescent-lighting equipment that have been developed. These specifications include those pertaining to ballasts and starters, which make for adequacy of parts that are so essential to the proper starting and operation of lamps. Today such equipment is available carrying certification as to suitability to serve fluorescent Mazda lamps.

Specifications also are available covering the RLM types of industrial equipment. RLM labels on industrial equipment to serve fluorescent lamps indicate the same degree of excellence that the RLM label on other equipment has stood for over a period of years.

The Fleur-O-Lier label on fluorescent-lighting equipment indicates that such equipment has been submitted to an authoritative testing laboratory and that it complies with the specifications under which Fleur-O-Lier manufacturers operate. Some 40 or 50 manufacturers of equipment are now supplying such fixtures. Equipment complying with these specifications makes for a higher standard of merchandise and service.

It should of course be recognized that all equipment carrying labels is not necessarily of equal quality. It may not all be of the best possible quality, or all adequate for all uses. However, labels on equipment, whether it is ballasts, starters, or completed fixtures, give definite assurance that the equipment measures up to certain minimum standards of excellence in electrical characteristics, mechanical construction, and lighting performance.

From a very modest beginning, the progress in fluorescent-lighting equipment during the last two and three quarters years has been such that the user now can get good equipment that will provide a sufficient amount of wattage to produce an adequate quantity of light in an interior; that will suitably distribute and control the light with a satisfactory minimum of brightness and glare; that is good mechanically and electrically, and, if appearance is a factor, is good to look upon. The fact that a generous assortment of lighting equipment incorporating all these essential characteristics is readily available in adequate quantity at reasonable costs indicates that the lighting-equipment industry has made very worth-while contributions, during less than three years, to the development of fluorescent lighting.

Survey of Fluorescent-Lighting Installations

PRESTON S. MILLAR
MEMBER AIEE

IT IS COMMON observation that numerous installations of fluorescent lighting violate illuminating-engineering principles that have been built up arduously through the years. In many instances where competent design could have taken advantage of the higher efficiency of these new illuminants to produce excellent light-

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Table II. Average Data for General and for Supplementary Fluorescent-Lighting Installations

(Electrical Testing Laboratories)

	General Lighting						Supplementary Lighting			
	Food and Drug Stores	Jewelry Stores	Other Retail Shops	Restaurants	Offices	Industrial	Show Cases	Show Cases and Wall Cases	Booths and Windows	Overhead Lighting
Number of installations	14	4	50	12	37	11	5	9	4	9
Average total watts	1,443	2,382	3,980	1,797	5,790	7,760	2,863	1,022	692	688
Average hours per year	3,188	3,035	2,824	4,299	2,251	2,568	2,684	3,231	1,400	2,542
Power-factor distribution (Per cent of installations)										
Above 0.90	85.7	75.0	74.0	58.4	81.1	100	60.0	44.4	50.0	66.7
0.80 to 0.89	0	0	8.0	8.3	0	0	0	11.1	0	0
Below 0.80	14.3	25.0	14.0	25.0	18.9	0	20.0	44.5	50.0	33.3
No information	0	0	4.0	8.3	0	0	20.0	0	0	0
Lamp sizes, distribution (Per cent of installations)										
15-watt	19.8	22.5	3.0	11.2	1.3	0	31.6	12.8	22.0	11.5
20-watt	2.1	0	6.0	10.3	1.6	0	0.2	0.8	5.2	61.3
30-watt	3.8	34.1	10.1	46.9	32.7	0	68.2	69.9	52.0	20.7
40-watt	74.3	43.4	80.9	31.6	64.4	100	0	16.5	20.8	6.5
Color, distribution (Per cent of installations)										
White	37.5	39.0	59.5	44.0	58.8	4.6	93.4	32.1	0	25.8
Daylight	57.8	61.0	40.3	40.0	41.2	95.4	6.6	67.9	100	71.0
Others	4.7	0	0.2	16.0	0	0	0	0	0	3.2

Table III. Costs Involved in Fluorescent-Lighting Installations

(Electrical Testing Laboratories)

	General Lighting						Supplementary Lighting			
	Food and Drug Stores	Jewelry Stores	Other Retail Shops	Restaurants	Offices	Industrial	Show Cases	Show Cases and Wall Cases	Booths and Windows	Overhead Lighting
Number of installations	14	4	50	12	37	11	5	9	4	9
Average number of lamps										
15-watt	6.64	14.00	2.58	5.25	1.62	0	28.8	3.88	5.67	2.78
20-watt	0.71	0	5.24	4.83	2.05	0	0.2	0.25	1.33	14.78
30-watt	1.29	21.25	8.82	22.00	42.43	0	62.0	21.25	13.33	5.00
40-watt	24.93	27.00	70.46	14.83	83.59	158.4	0	5.00	5.33	1.56
Total	33.6	62.3	87.1	46.9	129.7	158.4	91.0	30.4	25.7	24.1
Average total watts	1,443	2,382	3,980	1,797	5,790	7,760	2,863	1,022	692	688
Average hours burned	3,188	3,035	2,824	4,299	2,251	2,568	2,684	3,231	1,400	2,542
Average cost of installation										
Lamps and equipment*	$313 (13)	$776 (3)	$1,065 (43)	$571 (10)	$1,443 (35)	$2,424 (10)	$148 (4)	$319 (9)	$155 (3)	$199 (7)
Wiring**	66 (c)	192 (a)	270 (e)	139 (a)	411 (d)	2,357 (a)	15	89 (b)	8 (b)	116 (a)
Total	$379	$968	$1,335	$710	$1,854	$4,781	$163	$408	$163	$315
Average per lamp per installation	12.28	14.02	14.23	16.21	14.32	28.02	10.17	15.12	8.77	17.54
Average annual cost of lighting*	$209 (14)	$774 (3)	$640 (47)	$335 (11)	$868 (35)	$790 (11)	$374 (5)	$133 (9)	$42 (3)	$167 (8)
Average cost per lamp	6.24	11.21	7.63	6.87	6.79	4.99	4.11	4.93	2.25	6.19

*Numerals in parentheses indicate the number of installations for which cost data were available.

**Letters in parentheses indicate the number of installations for which the wiring cost was given as zero. (a) = 1, (b) = 2, (c) = 4, (d) = 12, (e) = 15.

ing effects, incompetent design has resulted in unsatisfactory illumination. Evidently the novelty of fluorescent lighting has attracted into the lamp manufacturing and selling business many people who are not equipped by training and experience to deal competently with the subject.

In an endeavor to collect information concerning the few installations of fluorescent lighting that are regarded as satisfactory by people who are acquainted with them, Electrical Testing Laboratories in the summer of 1940 distributed to electric-utility men a questionnaire designed to bring out the qualities of such installations. The survey proceeded falteringly through several months. Correspondents in some parts of the country reported that they knew of no satisfactory installations. Elsewhere correspondents sent in data for a few that were reported to be fairly satisfactory. Correspondence back and forth regarding lacking or questionable details of the data submitted consumed so much time that, in view of the rapid advance in this art, the material finally summarized may be almost obsolete.

Originally it had been planned to classify the material in order to arrive at descriptions of representative satisfactory installations in various types of interiors. It developed, however, that diversity of characteristics was so great and numbers of installations of a comparable character were so small that it was necessary to consolidate the data for several types of installations.

Tables II, III, and IV present some of the data secured. Briefly, the result of this not very satisfactory survey

makes available the following information. It must be dated as of 1940.

Most of the installations utilized 40-watt lamps with 30-, 15-, and 20-watt lamps following in the order named.

"White" and "daylight" lamps were about equally divided, the so-called daylight lamps being more largely used in food, drug, and jewelry stores, while the so-called white lamps were used more largely in retail stores.

Daylight lamps found place generally in industrial installations, while in auditoriums, automobile showrooms, and so on, white lamps predominated. Only in restaurants were lamps of other colors used to any considerable extent.

Most of the luminaires reported upon were of the direct-lighting type. Only about 30 per cent were shielded to reduce the observable brightness.

In these better installations power factors of the equipments were usually more than 85 per cent lagging.

The most commonly cited advantage of fluorescent lighting was the higher lighting intensities made available.

The most frequently cited disadvantage was flicker of light, which apparently was applicable mostly to installations in which neither flicker nor power factor was controlled.

In about 50 of the installations reported upon, data of watts consumed afforded comparison of present fluorescent- with preceding incandescent-lighting installations. The watts consumed in the fluorescent-lighting installations averaged about 93 per cent of the number consumed in the superseded incandescent-lamp installations. The fact that the range was from 25 to 229 per cent offers abundant indication of the opportunity that exists for varying lighting installations to secure new and better results and also to allow them to drift into inferiority.

Average foot-candles of course afford only a crude indication of lighting results. For what it is worth, however, the average shown by this survey of the better fluorescent-lighting installations was about 26 horizontal foot-candles. In the installations in which the illumination was measured at point of utilization the average was approximately 40 foot-candles.

These indications of the 1940 status of fluorescent lighting in its better applications leave one with a feeling of dissatisfaction concerning the probable lighting conditions in the installations not included in this survey. This feeling of dissatisfaction is accentuated by common observation. There is a great need for more intelligent application of fluorescent lighting.

Applications of Fluorescent Lighting

ARTHUR A. BRAINERD

THE fluorescent tube has certain desirable characteristics not possessed by its predecessors. Fundamentally, it is a low-brilliancy, large-area source, and good diffusion may be secured without the use of elaborate equipment. For high-level, localized general illumination, or uniform general lighting where low ceilings prevail, these characteristics are desirable. However, the light flux from this lamp cannot be projected great distances without loss which more than counterbalances its inherently high efficiency. The fluorescent lamp has the further advantage of being able to create a reasonably accurate reproduction of daylight, a characteristic which is a necessity in many specialized operations. Furthermore, a wide variety of colors may be secured without the use of absorption screens. In some cases this means nearly 200 times the usable light per watt.

While each individual problem must be studied on its merits, there are certain conditions under which some form of fluorescent lighting is obviously the most logical solution:

1. Since it is a long light source, the shadows are not harsh when mounted near the work, and in many cases, hardly noticeable at all.

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Figure 4. Fluorescent lighting is used for tubular knitting machines at a hosiery mill to secure 60 foot-candles of illumination with $3^1/_{10}$ watts per square foot

Table IV. Illumination Values

(Electrical Testing Laboratories)

	Installations in Which Foot-Candle Values Are Averages							Installations in Which Foot-Candle Values Are Known or Believed to Be at the Point of Utilization				
	No. of Installations	Total Watts	Watts Per Sq Ft	Avg. Foot-Candles	Applied Lumens Per Watt	Total Installation Cost	Cost Per Foot of Lamp Length	No. of Installations	Total Watts	Avg. Foot-Candles	Cost of Installation	Cost Per Foot of Lamp Length
Direct, exposed in both directions	28	Avg. 2,759	1.5	21	14.2	$ 648	$ 3.65	9	Avg. 4,658	51	$1,076	$3.57
		Max. 17,199	6.5	60	24.0	2,600	6.67		Max. 14,373	200	3,250	7.76
		Min. 159	0.4	2	5.0	33	1.77		Min. 588	15	165	1.95
Direct, exposed in one direction	15	Avg. 1,768	1.8	25	15.3	583	4.38	3	Avg. 3,087	30	850	3.22
		Max. 5,439	5.5	60	24.0	2,154	8.33		Max. 5,880	35	1,800	3.75
		Min. 160	0.5	11	10.9	100	2.54		Min. 736	24	200	2.55
Direct, concealed by glass	12	Avg. 5,544	2.2	32	14.0	3,073	4.80	5	Avg. 5,705	39	2,076	4.06
		Max. 20,825	5.2	85	19.2	16,565	9.34		Max. 11,779	60	6,000	6.29
		Min. 592	0.8	8	10.0	180	2.55		Min. 784	30	180	2.71
Direct, concealed by louvers	6	Avg. 5,562	2.7	34	13.3	2,023	3.60	1	Avg. 4,508	42	1,650	4.48
		Max. 19,600	4.3	41	15.8	8,200	5.16					
		Min. 1,176	1.8	24	7.0	210	2.05					
Direct indirect, exposed in both directions	3	Avg. 2,965	2.2	27	12.4	712	2.93	4	Avg. 2,671	25	623	2.60
		Max. 5,488	3.5	40	17.4	1,340	2.99		Max. 4,704	35	1,080	2.81
		Min. 760	1.7	20	8.9	185	2.83		Min. 1,568	15	340	2.34
Direct indirecj, exposed in one direction	4	Avg. 1,544	2.4	35	14.8	362	3.15	0				
		Max. 2,156	4.3	65	17.7	535	4.33					
		Min. 490	1.3	20	12.0	173	2.33					
Direct iodirect, concealed by glass	4	Avg. 4,688	1.7	20	10.9	977	7.86	0				
		Max. 9,016	3.4	45	13.2	2,105	16.67					
		Min. 444	0.9	8	8.9	227	2.86					
Direct indirect, concealed by louvers	6	Avg. 3,446	2.6	33	13.6	1,071	3.97	1	Avg. 1,764	45	500	3.47
		Max. 10,976	4.4	45	23.5	3,500	6.10					
		Min. 392	1.7	15	5.2	100	2.34					
Coves	13	Avg. 3,194	1.7	11	6.0	1,211	5.21	0				
		Max. 10,804	3.3	35	12.9	3,833	7.19					
		Min. 862	0.4	2	2.1	375	3.17					
Combination of direct and indirect, concealed by glass	1	39,113	2.6	36	13.8	12,000	3.78	0				

This is especially valuable where a workman's hands and body are continuously casting grotesque shadows under other systems.

2. The brightness of a 40-watt white tube is of the order of five candle-power per square inch. While this is too bright to be used in the direct line of vision, it is only a small fraction of the brightness of an incandescent filament or mercury vapor arc, and the direct reflections from polished surfaces are so low in brightness that even if these reflections do hit the eyes, the discomfort is negligible compared with that caused by other sources. In many cases, lighting levels of 100 to 200 foot-candles are required for seeing tasks of unusual severity. This requires relatively low hanging units of high lumen output. Fluorescent lighting, because it projects far less radiant heat, can provide such illumination quite comfortably.

3. Its characteristic high efficiency, coupled with the fact that it can be operated equally well on 110 or 220 volts, frequently make possible major improvements without an expensive rewiring job.

4. Where long burning hours are the general rule, the long life of the fluorescent tube is a distinct asset. Tubes operated continuously rather than intermittently usually will continue to give service far beyond their rated life.

5. Since this lamp is available in a variety of colors, interesting new decorative effects are now possible which were both difficult and expensive to secure with older sources.

6. The ability to approximate daylight in color quality is valuable, not only in operations where color must be identified, but also in bridging over the transition from daylight to 100 per cent artificial light.

Against these advantages, consideration must be given to the following:

1. The equipment is heavy and bulky, usually requiring supports at two points. Bulky equipment is sometimes objectionable from the standpoint of appearance, and in low-mounted localized systems may interfere with the work to be done.

2. Light fr om a fluorescent source is difficult to project any great distance and its light can never be concentrated in a small spot.

3. A multiplicity of low-output lamps increases the cost of maintenance. The problem of keeping lighting units free from dust is frequently serious and because of the long life of the fluorescent lamp, maintenance must be scheduled at regular intervals rather than cleaning only when lamps are replaced. It is never advisable to wait for a burnout before cleaning the reflectors.

4. At present, the cost of fluorescent equipment is rather high. This consideration, however, undoubtedly will become less weighty as the acceptance of this light source becomes more general.

INDUSTRIAL SEEING TASKS

The purpose of any industrial lighting installation is to enable the workers to see quickly, comfortably, and accurately. The primary object is strictly utilitarian, and pleasing appearance, while desirable, is a consideration decidedly secondary to the ability to produce favorable seeing conditions continuously, with minimum cost of maintenance. Much as we might desire it, there is no one best formula for good industrial lighting. Under certain conditions, as in textile work, shadowless illumination may be required; under other conditions, as in certain inspection operations, shadow or glint may be necessary. In a large foundry or assembly bay, uniform general illumination is the best solution, while in mass production assembly, high level localized lighting may be the only practicable solution. These are only a few of the many items which must be considered, and there is no one piece of equipment or light source which can reasonably be expected to solve all lighting requirements.

In all industrial lighting, the only illumination that

Figure 5. In the studio of a photoengraving company fluorescent lighting with continuous twin reflectors provides horizontal illumination of from 45 to 60 foot-candles

counts in production is that in the working area, while work is being done—*light where you work, when you work.* Many work areas are long and narrow. Such areas are quite common in the various textile industries and include such operations as silk hosiery knitting, weaving, spinning, spooling, winding, quilling, beaming, etc. In most of these operations, seeing is on both the vertical and horizontal planes. In applications of this nature, what is needed is a long narrow wedge of light projected in the working area with enough spill light to eliminate dark areas at wide angles of vision. For such areas, fluorescent lighting is logical and satisfactory.

Bench work of all kinds constitutes another condition where the work area is long and narrow. A continuous line of fluorescent tubing produces a very satisfactory field of light in the business area without discomfort from projected heat or glare. Assembly lines, or production lines of mass-production items, are physically the same as bench work. Such areas usually require relatively high levels of light and freedom from heat and reflected glare. Typical of such areas are radio-assembly lines; cutting and sewing tables in the garment industry; inspection and packing in such industries as glass-bottle making and candy making.

Special inspection operations have always been a problem for the lighting engineer and each one must be considered on its merits. Where color determination of textile fabrics or other manufactured products is involved, north skylight has been the standard for many years. In a large percentage of these cases, where daylight fluorescent lighting has been tried, it has proved satisfactory. However, the acceptance has not been unanimous.

For determining physical defects in woven fabrics, scribe marks on metal, defective workmanship in small metal parts, etc., the characteristic spectrum of the daylight fluorescent lamp, coupled with its low brilliancy, has proved a very acceptable and satisfactory answer.

High-Level Lighting for Fine Work. For many years we have known that lighting levels of 100 foot-candles and even higher were desirable for many delicate operations which place an unusual strain on the eyes. A degree of precision and accuracy in mass-production operations which was undreamed of a few years ago is now the accepted practice, and usually the seeing problem is one extending over long periods of time. Even the lowest-priced automobiles are constructed with tolerances of 1/1,000 of an inch or less. To provide the lighting levels necessary to carry on such fine work, some form of localized lighting is almost essential. Modern practice specifies a high level of uniform general illumination (at least 20 foot-candles), supplemented by a much higher level of lighting in the working area. For this supplemental lighting, a well-designed multitube fluorescent lighting unit offers a very satisfactory solution.

Other Localized Applications. For the localized lighting of woodworking machinery and machine tools such as lathes, drills, punch presses, millers, shapers, and boring machines, the new RLM fluorescent unit and several of the more specialized pieces of equipment give results that can be secured in no other way. White tubes used in connection with two-lamp auxiliaries reduce stroboscopic effect to a negligible value and thus contribute greatly to the safety of the worker. Where possible, such equipment should not be fastened to the machine, but rather suspended independently at a height that will not interfere with the workman. For the complete success of such an installation, only rugged equipment should be used, installed in such a way as not to detract from the appearance of the plant.

Imposing stones, folding and trimming, and proofreading areas, in the printing industry, have been successfully lighted. Problems of tobacco selection, cigarette and cigar manufacture, have been solved with the daylight lamp, usually through localized applications. Many installations of 40 or more foot-candles of general illumination for plant offices, file rooms, drafting rooms, and areas of like nature, are now in use.

APPLICATIONS FOR WHICH FLUORESCENT LAMPS ARE NOT SUITABLE

While it is inevitable that there should be border-line cases, there are certain industrial applications where, because of certain inherent qualities in the lamp itself, fluorescent lighting is not the best solution.

High Mounting Conditions. The most conspicuous illus-

tration of this point is the matter of lighting areas where, because of the nature of the operation, all lighting equipment must be mounted a considerable distance above the working plane. Such conditions obtain where traveling cranes or overhanging machine projections, which must be adjusted from time to time, and fabrication and assembly operations interfere with low hanging equipment. For such conditions, relatively few pieces of lighting equipment, each equipped with a high-power concentrated light source, furnish the most satisfactory solution. It is quite probable that where the mounting height exceeds 12 to 14 feet above the floor, the advantage of efficient redirection, plus the lower maintenance of 10,000-, 20,000-, and 30,000-lumen lamps, would indicate that the incandescent lamp or the high-pressure mercury tube will provide the most satisfactory solution of the problem.

Congested Areas. Another very definite handicap of present fluorescent equipment is its physical size. A 10,000-lumen (500-watt) incandescent Glassteel unit, for example, is only 20 inches in diameter and takes up only 2.6 square feet of area. To provide the same illumination from fluorescent sources would require five 40-watt white tubes. A two-tube (4,100 lumen) RLM unit takes up 6 square feet of area. In other words, the fluorescent equipment could be expected to take up at least five times as much space as the Glassteel for the same light output. For this reason, where machines have low projecting parts, or where the drive is by belt and line shafting, fluorescent lighting cannot be satisfactorily applied.

Dusty, Damp, and Hazardous Locations. Open fluorescent units, either for general or localized use, should not be used where dust and dirt will speedily impair their efficiency; and where dust or vapor explosive hazards exist, fluorescent lamps cannot be used, since no equipment meeting Class 2G, 2F, or 1D, hazardous locations, is available today.

COMMERCIAL APPLICATIONS

The term "commercial" as applied to lighting, includes both offices and sales areas. In contrast to industrial lighting with commercial lighting, favorable appearance is as important as easy, rapid, and accurate seeing.

As in industrial lighting, so in commercial lighting, there is no sure cure for all diseases. Under certain conditions as in show cases, heat characteristics alone confine the field almost exclusively to fluorescent lighting. For spot lighting displays in show windows, however, only a concentrated source such as the incandescent lamp can be logically considered. In between these two extremes are a multitude of locations where the choice is by no means self-evident. However, there are two general rules which must always apply:

1. The lighting system must provide comfortable and rapid seeing.
2. It must harmonize with its immediate surroundings.

In many commercial areas shadowless illumination from extended light sources is desirable, and projection of light is not involved. Frequently, a color approximating daylight is invaluable, and splashes of colored light constitute a distinct decorative asset. Under such conditions fluorescent lighting may be a logical and highly satisfactory method of producing the desired results.

General Lighting of Sales Areas. While the most effective way of utilizing the fluorescent light is in continuous lines, there are many satisfactory multitube fluorescent units on the market which produce quite a satisfactory seeing result when mounted on correctly spaced outlets. Since the trend in commercial lighting is toward continually higher levels, it is by no means good business to utilize the higher efficiency of the fluorescent lamp to lower the electric bill. A modern four-tube 200-watt commercial unit gives out approximately 8,500 lumens as compared to 10,000 lumens for a single 500-watt filament lamp. This fact should be taken into consideration in determining the spacing. The most effective general lighting with fluorescent sources can be done when it is built into a room in continuous lines.

Because of its low temperature, fluorescent lighting is almost ideal for show-case lighting, although in certain isolated cases color distortion and fading have been reported.

Daylight fluorescent lamps have become quite popular for fitting mirror and color-matching purposes and probably

Figure 6. A men's clothing store uses fluorescent lamps mounted and built in porcelain enamel units, and providing 85 foot-candles of illumination when installed

should be used for all except the most critical color-matching requirements. Garments that are to be worn in the evening should, of course, be displayed under incandescent light.

For silhouette signs and local display identification fluorescent lighting is almost ideal, because of its size. It produces very uniform results.

For all except very low-ceilinged show windows, the filament lamp continues to be the basic light source. The fluorescent lamp, if used at all, should be for producing a general flood of light and should be augmented by filament lamps in suitable projection equipment. Frequently, silvered reflector lamps in combination with fluorescent lamps insure a happy solution of the show-window lighting problem.

Office Lighting. This class of lighting falls under two general headings. The first and most extensive is the lighting of large office buildings. Where the ceilings are low, fluorescent lighting has a distinct advantage over the filament lamp, particularly where the wiring is inadequate for high-level incandescent lighting. Here the high initial cost of fluorescent equipment may be largely offset by the decreased cost in wiring changes. Moreover, fluorescent lighting equipment can be mounted close to the ceiling or even countersunk flush with sound proofing, thus producing a more spacious effect.

However, modern incandescent luminaires produce fully as satisfactory illumination with much less equipment to maintain. Office luminaires are now available using the 750-watt and 1,000-watt bi-post incandescent lamp which produce excellent illumination without glare, even on very low ceilings. Such practice insures a minimum of maintenance expense. Indirect luminaires using silvered bowl lamps are also quite effective and have the added advantage that every lamp replacement means a brand new reflector.

The choice of a lighting system for office-building service calls for an accurate analysis of fixed and operating costs of both systems. In the case of rentable offices the novelty of fluorescent lighting may be a strong enough factor in attracting new tenants to justify the initial capital investment and increased maintenance.

For small offices attached to stores or industrial plants, fluorescent lighting has certain distinct advantages where ceilings are broken up by steam pipes or other obstructions which prevent any satisfactory lighting installation with indirect or luminous indirect incandescent systems. Where such obstructions do not exist, the choice of a fluorescent system would be largely one of personal preference.

A SPECIALIZED SEEING TOOL

To sum up the situation, the fluorescent lamp is one of three generally available modern artificial light sources which has certain characteristics not possessed by either of its competitors. Fluorescent lighting should not be considered at the present time where light must be projected over 12 or 14 feet; where a concentrated spot of light is required; or where, because of its physical size, it becomes an obstruction. There are many seeing problems which can be very readily solved with fluorescent lighting, concerning which there is little doubt as to choice. There are also many other seeing tasks which can be satisfactorily solved with incandescent or high-pressure mercury lamps, as well as with fluorescent. In some cases a combination of two different light sources offers a logical solution. The ultimate choice will depend upon the personal preference of the buyer. Lastly, there are some seeing tasks for which fluorescent lighting is quite unsuitable, and for such locations it should be very definitely ruled out.

The fluorescent lamp is without question the most efficient light source available today, if we consider only the number of lumens emitted per watt, but we should not forget that the purpose of a lighting system is to produce not only light, but the best possible seeing conditions for the task at hand, with a minimum of operating and maintenance expense. Unless these conditions are produced, no lighting system can be described as efficient, and the cost of installation and operation of any lighting system will be satisfactory only when the special advantages of the light source are applied as a solution to the work problem involved.

When used for localized lighting at mounting heights of 2 to 5 feet over the working area, fluorescent lamps of the 30- and 40-watt sizes should be used with a minimum of 2 watts per square foot, and 3 to 5 watts per square foot will produce 50 or more foot-candles for very satisfactory performance. For general illumination the longer more efficient tubes should be used and $1^{3}/_{4}$ watts per square foot, or more, has provided seeing results that have inspired unusually favorable comment. These values are to be considered as present-day minimums and frequently much more illumination can be used with profit.

Multiple-lamp units eliminate stroboscopic effects when two-lamp auxiliaries are used and power factor is raised to near unity. Definite consideration must be given to high-power-factor equipment if penalties are to be avoided and if full efficiency of the wiring system is to be obtained. High-power-factor reactors are available, or corrective equipment in the form of capacitators may be used to bring the system to 90 per cent power factor, and such equipment should be installed.

While fluorescent lighting is here to stay, the other light sources have a definite place in industry and will probably continue to be used for many years to come. For this reason, before making any major changes in an industrial lighting system, it is advisable to compare the characteristics of the various light sources available and make the final selection on the basis of ability to create the best seeing conditions.

Industrial lighting is now in a transition stage in which new discoveries and new methods are continuously being made available. At such a time it seems rather trite to say that rapid obsolescence is the order of the day. The danger is not that we may adopt something wrong, but rather that, in our eagerness to be up to date, we may expect too much improvement from a poorly planned and inadequate fluorescent system.

Calculation of Fault Currents in Industrial Plants

RAYMOND C. R. SCHULZE

A detailed example illustrates the application of a method of calculating fault currents, knowledge of which becomes increasingly important as the rate of industrial expansion accelerates

THE calculation of fault currents at low voltages has been, until recently, a somewhat neglected subject. No new theory or practice is involved, but two things are necessary: an understanding that *all* parts of the system must be included at low voltages, and the extension of tables and curves to include the conductor sizes and configurations found at low voltages. For example, at 220 or 440 volts, even a ten-foot section of bus will have some bearing on the magnitude of the short-circuit current. Therefore, it is important that everything be included in the final reactance figure. Furthermore, the information should be put into a form which is easily understood.

This article is one attempt to solve these problems. The data have been put into a convenient form, and the sample problem gives the reasoning concerned with the various steps, as well as the calculations themselves.

Faults can be divided into four groups. The relative values of fault current are:

Short circuits

Three phases to ground or free of ground	1.00
Between two-phase wires, no ground	0.87

Grounds—with solid neutrals

One phase to ground or two phases to ground:	
Impossible to give any general rule.	
At neutral-grounded transformer	Probably more than 1.00
Some distance from neutral-grounded transformer	Less than 1.00

These figures are for comparative purposes only, and are intended to indicate that the three-phase fault current—the easiest one to calculate—will give a good idea of the magnitude of the current for any type of fault. Certainly a knowledge of the three-phase fault current is much better than none at all.

The calculations assume that:

1. A solid copper-to-copper connection exists between all phases at the point of short circuit. There is no allowance for arc or fault resistance.

2. The power supply is from a private utility system, so that the current value is independent of time (after the first few cycles). If the industrial plant has generators of its own, then the current will decrease as the time from the instant of fault increases, because of demagnetization of the plant's generators.

3. If fuses operating in one cycle or less are used, the value of current which the fuse may interrupt may be 1.73 times the value calculated here.

Only three-phase faults will be considered. They are the easiest to calculate, and they give an indication of fault conditions sufficient for most purposes.

The only equation necessary is Ohm's law

$$I = \frac{E_n}{X} \qquad (1)$$

where

I = amperes per phase (same value in each phase).
E_n = volts from phase to neutral = 0.577 × volts from phase to phase.
X = ohms reactance, from the internal voltages of the generators, to the fault.

The determination of the value of X is the difficult part of setting up this equation.

The exact value of fault current will be obtained by

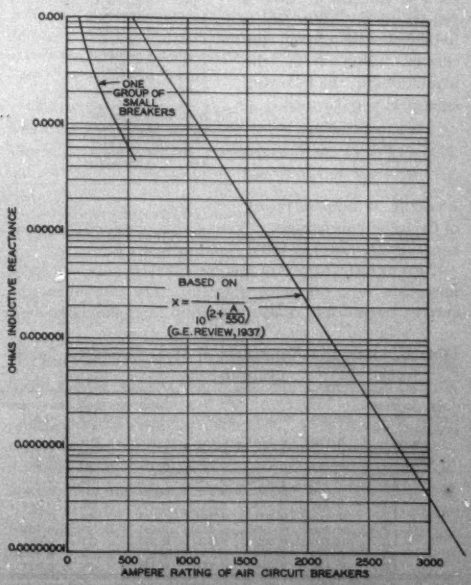

Figure 1. Inductive reactance of air circuit breakers

Presented informally at the conference on power distribution in industrial plants at the AIEE 1941 winter convention, Philadelphia, Pa., January 27–31.

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1. For all numbered references, see list at end of article.

using the impedance, where the impedance Z is equal to $\sqrt{R^2+X^2}$. In general, however, the values of X will be sufficiently greater than those of R that the reactance alone can be used without introducing too great an error. This statement is particularly true of transformers, generators, and reactors. It also applies to open-wire or open-bus construction for conductor sizes greater than 250,000 circular mils. For three-conductor cables, the resistance may be close to the reactance, but in general the reactances will be a little greater for conductor sizes in excess of 500,000 circular mils. Of course greater accuracy would be obtained by using the impedance, but generally the use of reactance is entirely satisfactory.

For the computation of reactance, the system can be divided into four general classes:

1. Air circuit breakers
2. Current transformers
3. Multiconductor cables
4. Open-wire circuits

The reactance of an air circuit breaker is almost entirely due to the trip coil itself. Values obtained for the same size of circuit breaker vary considerably, so it is difficult to give a general value. When it is impossible to obtain the correct value from the manufacturer, the following equation[1] may be used.

$$X_{acb}=\frac{1}{10^{\left(2+\frac{A}{600}\right)}} \qquad (2)$$

where A = ampere rating of the air circuit breaker. Values of X obtained from this equation are given in table I and in figure 1.

Current transformers of low current rating are especially important in a reactance diagram. The burden on the current transformer is also important, and should be estimated for each one in the system. The following equation[1] gives the impedance of a current transformer, and figures 2, 3, and 4 present this equation in graphical form. While current transformers of high current ratings do not affect fault currents particularly, those of low current ratings have considerable effect on fault currents at low voltages.

$$Z_{ct}=\frac{42.5+B}{I_p^2} \qquad (3)$$

where

B = secondary burden in volt-amperes
I_p = primary amperes, rating

Typical values of the volt-ampere burdens of various relays and meters are given in the "Relay Handbook Supplement".[2]

Multiconductor cables are handled in the usual way. Existing tables can be used. Table II gives some typical values.

The designation "open-wire circuits" covers everything else in the distribution system. This refers to the usual three-phase line, or to buses or circuits made up of two or more conductors per phase, to bus work made up of flat bars, and is also used to include disconnecting switches and oil circuit breakers as parts of an open-wire circuit.

The reactance of the usual three-phase circuit made up of one conductor per phase is obtained in the usual manner. Any table of reactances of transmission lines may be used.

Since most tables do not cover the full range of large

Table I. Inductive Reactance of Air Circuit Breakers
(60 Cycles)

Amperes	Values Given by Hanna[1]	Small Breakers
20		0.020
35		0.007
50		0.003
70		0.002
100		0.0009
150		0.0004
200		0.0003
250		0.0003
300		0.0002
350		0.0001
400	0.00185	0.0001
500		0.000050
550	0.001000	0.000050
600	0.000811	0.000050
700	0.000534	
800	0.000351	
900	0.000231	
1,000	0.000152	
1,100	0.000100	
1,200	0.000066	
1,300	0.000043	
1,400	0.000028	
1,500	0.000019	
1,650	0.000010	
1,800	0.0000042	
2,000	0.0000022	
2,200	0.0000010	
2,400	0.00000040	
2,600	0.00000019	
2,800	0.00000008	
3,000	0.000000035	

Table II. Inductive Reactances of Three-Conductor Cables
Ohms Per Mile

Conductor Size					0000	00	1
Circular Mils		500,000	400,000	300,000	211,600	133,225	83,521
Resistance ohms Per Mile		0.116	0.145	0.194	0.275	0.437	0.695
5/32 inch	X	0.127	0.129	0.132	0.135	0.139	0.145
	Z	0.172	0.195	0.235	0.308	0.480	0.711
1/4	X	0.131	0.134	0.136	0.140	0.146	0.152
	Z	0.175	0.197	0.237	0.309	0.461	0.713
9/32	X	0.136	0.138	0.141	0.146	0.153	0.162
	Z	0.178	0.201	0.240	0.313	0.464	0.715
5/16	X	0.146	0.149	0.154	0.161	0.171	0.182
	Z	0.186	0.208	0.246	0.320	0.471	0.697
23/64	X	0.153	0.157	0.162	0.170	0.182	0.195
	Z	0.192	0.230	0.254	0.323	0.474	0.721

From Westinghouse Electric and Manufacturing Company switchgear data book.

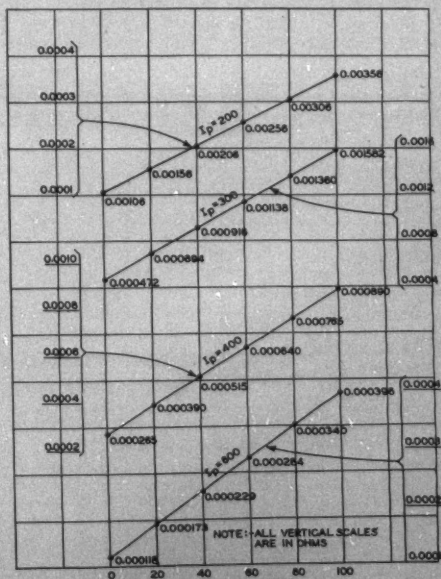


Figure 2. Impedances of current transformers with ratings of 200, 300, 400, and 600 amperes

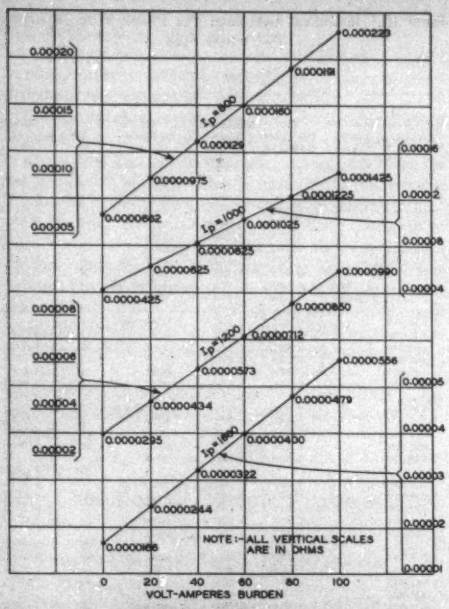


Figure 3. Impedances of current transformers with ratings of 800, 1,000, 1,200, and 1,600 amperes

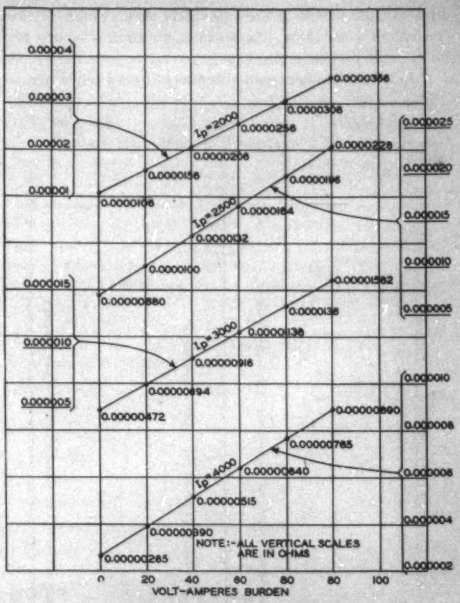


Figure 4. Impedances of current transformers with ratings of 2,000, 2,500, 3,000, and 4,000 amperes

wire sizes and small spacings encountered in low-voltage problems, the more complete and compact table III has been prepared. This table was prepared primarily for use on low-voltage short-circuit problems, where the conductor size may be in millions of circular mils. Any conductor can be replaced, in reactance equations, with an equivalent one, the equivalent conductor being a thin copper tube of radius $0.779R$. The reactance in ohms per 1,000 feet of one conductor of a circuit is

$$X = 0.0529 \log_{10} \frac{D}{R}$$

$$= 0.0529 \log D - 0.0529 \log R$$

These separate terms are given in columns 4 and 6 of table III. To find the reactance per phase, look up the proper values in columns 1 and 5, read the corresponding figures in columns 4 and 6, and subtract column 4 from column 6. The answer is ohms per 1,000 feet.

Example: Reactance of 250,000 circular-mil circuit, 36-inch spacing

$D = 36$ inches

column 6 = 10.0824 − 10

column 4 = 9.9653 − 10

0.1171 − 0

Nesbit[3] gives 0.1174. The new table may not be correct in the fourth place.

Column 3 of table III gives values of the equivalent mean radius R_{01} for use with the nomogram for equivalent mean radius of two-conductor group (figure 5).

If the spacings between the three conductors are all different, the spacing in column 5 of table III should be

$$D_{ab} = \sqrt[3]{D_{12} \times D_{23} \times D_{13}}$$

Where there is more than one conductor per phase, whatever the shape or size of these conductors, the first step is to convert all the conductors of any one phase into one equivalent conductor. This circuit of three equivalent conductors (one per phase) then is calculated as a conventional three-phase circuit.

One common case is the use of two round conductors per phase. To find the radius of the "equivalent conductor", use table III and figure 5. Column 3 of table III gives the equivalent mean radius of one actual conductor. On figure 5, place a straight edge between this value of equivalent mean radius of one actual conductor (left scale) and the distance between the two conductors of one phase (right scale); the left side of the center scale will give the equivalent mean radius of the equivalent conductor that replaces the two actual conductors. This process is made clearer by item 2 of the sample problem that follows.

Table IV gives values of ohms per phase for some conductor sizes and spacings used in past calculations.

Bus structures frequently are made up of flat copper bars, often with two or more bars per phase. All the bars in one phase group must be reduced to one equivalent conductor for that phase. The calculation of this equivalent conductor is slightly complicated. Table V gives

approximate values of the equivalent mean radius of this equivalent conductor, for various numbers of bars per phase, and various sizes of bars.

Oil circuit breakers and disconnecting switches are to

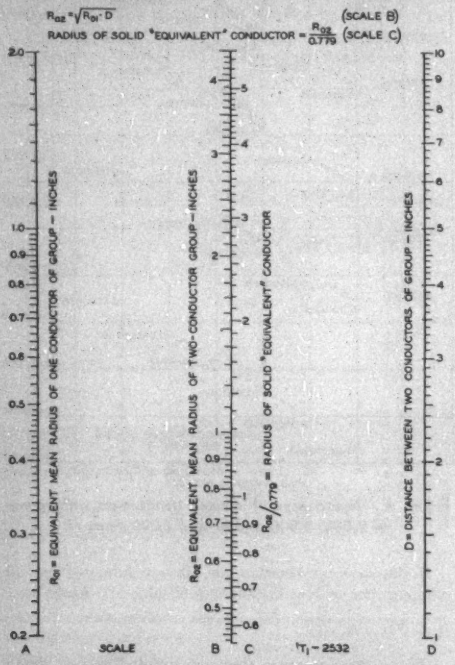

$R_{02} = \sqrt{R_{01} \cdot D}$
(SCALE B)
RADIUS OF SOLID "EQUIVALENT" CONDUCTOR = $\frac{R_{02}}{0.779}$ (SCALE C)
R_{01} = EQUIVALENT MEAN RADIUS OF ONE CONDUCTOR OF GROUP — INCHES
R_{02} = EQUIVALENT MEAN RADIUS OF TWO-CONDUCTOR GROUP — INCHES
$R_{02}/0.779$ = RADIUS OF SOLID "EQUIVALENT" CONDUCTOR
D = DISTANCE BETWEEN TWO CONDUCTORS OF GROUP — INCHES
SCALE
$T_1 = 2532$
A
B
C
D

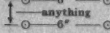
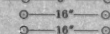
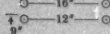
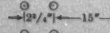
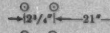
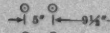
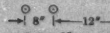
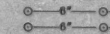
Figure 5. Equivalent mean radius of two-conductor group

Table III. Inductive Reactance Per Phase Wire in Ohms Per 1,000 Feet

All Dimensions in Inches

(1) Circular Mils	Wire Size	(2) Diameter Stranded	(3) Equivalent Mean Radius	(4) 0.0529 × log K_a	(5) D_{ab}	(6) 0.0529 × log D_{ab}
	6	0.184	0.0668	9.9378–10	1.0	0.0000
	5	0.206	0.0748	.9404	1.5	0.0093
	4	0.232	0.0843	.9432	2	0.0159
	3	0.260	0.0944	.9458	3	0.0252
	2	0.292	0.1060	.9484	4	0.0319
	1	0.332	0.126	.9524	5	0.0370
	0	0.373	0.1413	.9553	6	0.0412
	00	0.418	0.158	.9576	7	0.0447
	000	0.470	0.178	.9603	8	0.0478
211,600	0000	0.528	0.200	.9630	9	0.0505
					10	0.0529
250,000		0.575	0.221	9.9653–10		
300,000		0.630	0.242	.9674	11	0.0551
350,000		0.681	0.262	.9692	12	0.0571
400,000		0.728	0.2795	.9707	13	0.0589
450,000		0.772	0.2965	.9721	14	0.0607
500,000		0.814	0.3125	.9733	15	0.0622
					16	0.0637
600,000		0.893	0.345	9.9755–10	17	0.0651
700,000		0.964	0.372	.9773	18	0.0664
800,000		1.031	0.398	.9788	19	0.0677
900,000		1.093	0.422	.9802	20	0.0688
1,000,000		1.152	0.445	.9814		
					21	0.0700
1,100,000		1.209	0.467	9.9825–10	22	0.0710
1,200,000		1.263	0.489	.9836	23	0.0721
1,300,000		1.315	0.509	.9845	24	0.0730
1,400,000		1.364	0.529	.9854	25	0.0740
1,500,000		1.412	0.546	.9861		
					26	0.0749
1,600,000		1.459	0.565	9.9869–10	28	0.0766
1,700,000		1.504	0.584	.9876	30	0.0782
1,800,000		1.548	0.600	.9883	32	0.0797
1,900,000		1.590	0.616	.9889	34	0.0810
2,000,000		1.631	0.633	.9895	36	0.0824
					38	0.0836
		1.7	0.661	9.9905–10	40	0.0848
		1.8	0.700	.9918		
		2.0	0.779	.9943	42	0.0859
		2.2	0.856	.9964	45	0.0875
		2.4	0.935	.9985	50	0.0899
		2.7	1.050	10.0011–10	55	0.0921
		3.0	1.169	.0038	60	0.0941
		3.5	1.361	.0071	65	0.0959
		4.0	1.558	.0102	70	0.0976
		5.0	1.948	.0153	80	0.1007
		6.0	2.338	.0195	90	0.1034
		8.0	3.116	.0261	100	0.1058
		10.0	3.895	.0312	120	0.1100

Table IV. Various Configurations and Reactances for Use in Station Service Bus Calculations

Configuration	Wire Size	No. of Phases	Drop Per Mile (Per Cent)*	Ohms Per Phase Per Mile	Ohms Per Phase Per 1,000 Feet
	1,500,000	See note†		0.318†	0.0602†
	750,000	3		0.4798	0.09085
	1,500,000	3		0.4378	0.0828
	1,500,000	3		0.2635	0.0499
	1,500,000	3		0.3825	0.0725
	1,500,000	3		0.4175	0.079
	1,750,000	3		0.3178	0.0601
	2,250,000	3		0.3205	0.0607
	1,000,000	2	26.3	9.55**	1.81**
	1,500,000	2	24.25	8.81**	1.67**

* Per cent drop at 4,800 kva, 2,400 volts.

† Note: Assumed to be two independent three-phase circuits; ohmic values are per circuit.

** Equivalent three-phase ohms at 13 kv.

be considered as parts of the three-phase circuits in which they are located.

In these calculations, no account is taken of the effect on the reactance of loops and angles in the open-wire circuits or bus structures.

The reactance of conductors in a nonmetallic conduit depends only on the conductor diameter and spacings. If the conductors are in an iron conduit, however, the reactances will be increased somewhat due to the presence of the iron. Test data on this effect have been presented by L. Brieger[4] of the Consolidated Edison Company of New York, Inc. These test data show that for the cases studied, the resistance would increase by a small percentage, but the reactance might increase by considerable percentages. Where the effect of the iron conduit must be known accurately, it is suggested that a measurement be made of the reactance of the particular feeder, or one like it.

Complete calculations for one example follow, illustrating the theory and the use of the reactance data presented.

Solution of Sample Problem

CALCULATION OF REACTANCES (FIGURE 6)

(*1*) *Customer's Generator, 500 Kva, 20 Per Cent Reactance*

This is assumed to be a relatively slow speed machine with salient poles; therefore it has a high reactance.

$X = E/I$

I at full load $= \dfrac{500{,}000}{3\times 277} = \dfrac{500{,}000}{831} = 602$ amperes

E = volts drop across machine reactance

$= \dfrac{20}{100}(277) = 55.4$ volts

$X = \dfrac{55.4}{602} = 0.092$ ohm

(*2*) *Customer's Generator, 500 Kva, 5 Per Cent Reactance*

This is assumed to be a turbogenerator, high speed, with nonsalient poles; therefore it has a low reactance.

By formula

$$X = \frac{\%X10(\text{kv}_{L-L})^2}{3\,\phi\ \text{kva}}\ \text{ohms}$$

$$= \frac{5(10)(0.48)^2}{500} = \frac{5(10)0.23}{500}$$

$= 0.023$ ohm

(*3*) *Utility System*

It is not always important to have the exact value of the reactance of the utility system, since it is usually a small part of the total value of parts 3, 4, 17, 5, 11, and 18 on the diagram (figures 6, 7, and 8); a large percentage error in the utility system reactance becomes a small percentage error in the total. If possible, the utility system reactance should be obtained from the utility system's engineers. If not obtainable, it should be estimated.

In this case, the utility system reactance is assumed to be 0.60 ohm at 4,150 volts; on the 480-volt base the system reactance is

$$\left(\frac{480}{4{,}150}\right)^2(0.60) = 0.0134(0.60) = 0.008\ \text{ohm}$$

It is necessary to convert all reactances to equivalent ohms at the same voltage base, as shown.

Table V. R_0 Values for Flat Copper Bars (Approximate)

Based on $R_0 = 0.2235\ (a+b)$

Size (Inches)	$a+b$	R_{01} (Inches)	R_0 for Several Bars in Parallel (Inches) 2	3	4	5	6
1/4 by 2	2.25	0.504	0.502	0.585	0.685	0.790	0.893
1/4 by 3	3.25	0.727	0.602	0.660	0.750	0.849	0.949
1/4 by 4	4.25	0.950	0.689	0.722	0.803	0.896	0.993
1/4 by 5	5.25	1.173	0.766	0.775	0.846	0.934	1.030
1/4 by 6	6.25	1.397	0.838	0.821	0.883	0.967	1.058

For 2 bars, $R_{01} = \sqrt[3]{R_{02}} = 0.707\sqrt{R_{01}}$ For 5 bars, $R_{05} = 0.905\sqrt[5]{R_{01}}$

For 3 bars, $R_{03} = 0.735\sqrt[3]{R_{01}}$ For 6 bars, $R_{06} = 1.005\sqrt[6]{R_{01}}$

For 4 bars, $R_{04} = 0.813\sqrt[4]{R_{01}}$

NOTE 1. Spacing between center lines of bars = 0.50 inch.

NOTE 2. R_0 is a thin copper tube; when using tables (as in Nesbit[2]) divide these values by 0.779 to get the corresponding radius of a solid conductor.

(*4*) *Transformer, 1,000 Kva (Three 333-Kva One-Phase Units), 3 Per Cent X, 4,150/480 Volts*

By formula

$$X = \frac{3(10)(0.480)^2}{1{,}000}$$

$$= \frac{3(10)0.23}{1{,}000}$$

$= 0.0069$ ohm

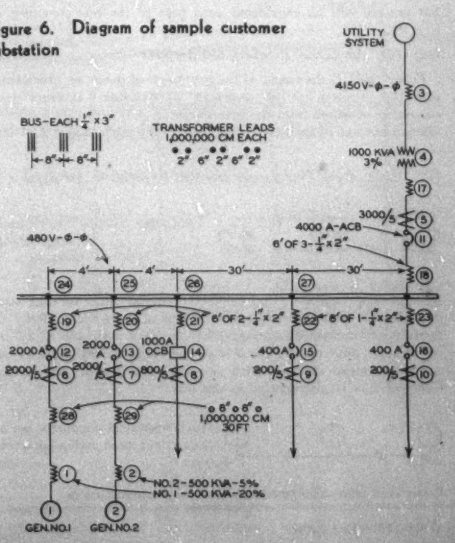
(*5*) *Current Transformer, 3,000/5 Amperes*

Burden:

	Volt-Amperes
Ammeter	2
Watt-hour meter	4
Overload relay	10
Directional overcurrent relay	14
Total	30

From figure 4, the impedance of this current transformer is 0.000008 ohm.

Figure 6. Diagram of sample customer substation



(6) (7) *Current Transformers, 2,000/5 Amperes*

Burden:

	Volt-Amperes
Ammeter	2
Wattmeter	2
Power-factor meter	4
Watt-hour meter	4
Overload relay	10
Directional overcurrent relay	14
Total	36

From figure 4, the impedance of each current transformer is 0.0000195 ohm; call it 0.000020 ohm.

(8) *Current Transformer, 800/5 Amperes*

Burden:

	Volt-Amperes
Ammeter	2
Watt-hour meter	4
Overload relay	10
Total	16

From figure 3, $Z = 0.000091$ ohm.

(9) (10) *Current Transformers, 200/5 Amperes*

Burden:

	Volt-Amperes
Wattmeter	2
Ammeter	2
Total	4

From figure 2, $Z = 0.0012$ ohm each.

(11) *Air Circuit Breaker, 4,000 Amperes*

The reactance of this air circuit breaker is about 0.0000000001 ohm, and can be neglected.

(12) (13) *Air Circuit Breakers, 2,000 Amperes*

From table I, the reactance of these breakers is probably less than 0.0000022 ohm each.

(14) *Oil Circuit Breaker, 1,000 Amperes*

Because this is an oil breaker, it will not be calculated separately, but instead will be considered as a part of the bus structure of item 21.

(15) (16) *Air Circuit Breakers, 400 Amperes*

From table I, the range of the reactance of these air breakers is probably between 0.00185 ohm and 0.00010 ohm. If exact data cannot be obtained from the manufacturer, it is probably better to take an average of the two limits given by the table, about 0.001000 ohm.

(17) *Leads From Transformer 480-Volt Bushings to Air Breaker*

1,000,000 circular mils each, length 12 feet

In table III, column 1, find 1,000,000 circular mils; for this size, in column 3, read equivalent mean radius of 0.445 inch. Refer to figure 5; set a straight edge at 0.445 on the *A* scale and at 2.0 on the *D* scale, and read on the *B* scale the value of 0.942 inch as the equivalent mean radius of each two-conductor group. The actual leads can now be represented in this way:

Each equivalent conductor has an equivalent mean radius of 0.942 inch

Equivalent triangular spacing of the three conductors is

$\sqrt[3]{8(8)(16)} = 10.1$ inches

Refer again to table III. Values must be obtained from columns 4 and 6 for 0.942 inch in column 3 and 10.1 inches in column 5, respectively.

Column 3	Column 4
1.050	10.0011 − 10
.935	9.9985 − 10
0.115	0.0026

$0.942 - 0.935 = 0.007$

$\frac{0.007}{0.115}(0.0026) = 0.00016 = 0.0002$

For 0.942, the value is $(9.9985 - 10) + 0.0002 = (9.9987 - 10)$

Column 5	Column 6
11	0.0551
10	0.0529
1.0	0.0022

$0.1/1.0(0.0022) = 0.00022$

For 10.1 the value is $0.0529 + 0.0002 = 0.0531$

Value from column 6 10.0531 − 10
Value from column 4 9.9987 − 10

0.0544 ohm per phase per 1,000 feet

$\frac{12}{1{,}000}(0.0544) = 0.000652$ ohm per phase for 12 feet of leads.

(18) *Leads From Air Breaker to Bus*

Each phase is made up of three ¼" by 2-inch bars

In table V, the equivalent mean radius of one equivalent conductor which will replace three bars of ¼" by 2-inch size (top row, fifth column from left) is 0.585 inch. It should be understood that this value of 0.585 is probably low, thus giving a value of reactance higher than actual, since skin and proximity effects were neglected.

The remaining procedure is the same as in the last two-thirds of the discussion under item 17.

$\sqrt[3]{8(8)(16)} = 10.1$ inches

Column 3	Column 4
0.600	9.9883 − 10
0.584	9.9876 − 10
0.016	0.0007

$\frac{0.001}{0.160}(0.0007) = 0.000004$

For 0.585 use 9.9876 − 10
From column 6 10.0531 − 10
From column 4 9.9876 − 10

0.0655 ohms per phase per 1,000 feet

For 6 feet

$$X = \frac{6}{1{,}000}(0.0655) = 0.00039 \text{ ohm per phase}$$

(19) (20) *Leads From Generator Air Breakers to Bus*

Each phase is made up of two ¼" by 2-inch bars

From table V, read equivalent radius of 0.502 inch. Equivalent spacing is 10.1 inches.

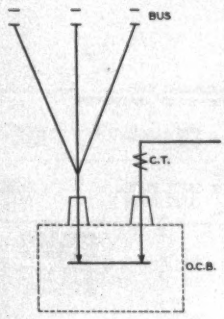
0.509	9.9845 − 10
0.489	9.9836 − 10
0.020	0.0009

$(0.013/0.020)(0.0009) = 0.00058$

For 0.502 use 9.9842 − 10
From column 6 10.0531 − 10
From column 4 9.9842 − 10
0.0689 ohms per phase per 1,000 feet

For 6 feet

$$X = \frac{6}{1{,}000}(0.0689) = 0.000414 \text{ ohm.}$$



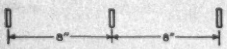
(21) Leads From Bus Through Oil Breaker to Current Transformer

In this case the reactance of the copper in the circuit-breaker bushings is considered as part of the "open-wire" construction from the bus to the current transformer. The total length from the bus to the current transformer is assumed to be 12 feet. Since the reactance per foot of length does not change much as the configuration changes, and a detailed calculation would take considerable time, it seems to be sufficiently accurate to consider the whole 12-foot length as being made up in the same way as the 6 feet of leads from the bus to the breaker.

These leads are two 1/4- by 2-inch bars (same arrangement as in items 19 and 20) so the reactance of item 21 becomes

$$\frac{12}{6}(0.000414) = 0.00083 \text{ ohm}$$

(22) (23) Leads From Bus to Feeder Air Circuit Breakers



One 1/4-by 2-inch bar per phase

From table V, read equivalent radius of 0.504 inch (in column headed R_{01}). Equivalent spacing is 10.1 inches.

0.509	9.9845 − 10
0.489	9.9836 − 10
0.020	0.0009

(0.015/0.020) (0.0009) = 0.0007

For 0.504 use 9.9843 − 10

From column 6 10.0531 − 10
From column 4 9.9843 − 10
0.0688 ohms per phase per 1,000 feet

For 6 feet

$$X = \frac{6}{1{,}000}(0.0688) = 0.000414 \text{ ohm}$$

(24) (25) Main Bus

Each phase is made up of three 1/4- by 3-inch bars

The procedure is the same as in items 18 to 23.
From table V, for size 1/4 by 3 inches, three bars in parallel, the equivalent radius is 0.660 inch. Equivalent spacing is 10.1 inches.
From table III,

Column 3	Column 4
0.661	9.9905 − 10
0.633	9.9895 − 10
0.028	0.0010

(0.027/0.028) (0.0010) = 0.00097 = 0.0010

For 0.660, use 9.9905 − 10
From column 6 10.0531 − 10
From column 4 9.9905 − 10
0.0626 ohms per phase per 1,000 feet

For 4 feet of bus length

$$X = \frac{4}{1{,}000}(0.0626) = 0.00025 \text{ ohm}$$

(26) (27) Main Bus

Same arrangement as in items 24 and 25, so that ohms per phase per 1,000 feet are the same, but the length is different.
For 30 feet

$$X = \frac{30}{1{,}000}(0.0626) = 0.00188 \text{ ohm}$$

(28) (29) Generator Leads

Each phase is one 1,000,000 circular-mil conductor. Distance, generator to current transformer, 30 feet

From table III, equivalent mean radius of one phase conductor is 0.445 inch. Equivalent spacing is 10.1 inches.

From column 6 10.0531 − 10
From column 4 9.9814 − 10
0.0717 ohms per phase per 1,000 feet

For 30 feet

$$X = \frac{30}{1{,}000}(0.0717) = 0.002160 \text{ ohm}$$

These reactance figures now can be placed on the diagram as shown in figure 7. This figure also shows the assumed fault locations.

CALCULATIONS OF FAULTS (FIGURES 7 AND 8)

Fault at (A)

From utility system:

0.0080
0.0069
0.0149 ohm

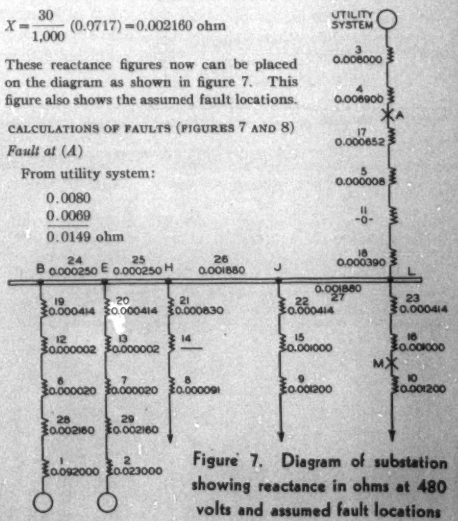


Figure 7. Diagram of substation showing reactance in ohms at 480 volts and assumed fault locations

1 to B	2 to E	1 to B to E
0.092000	0.023000	0.094596
0.002160	0.002160	0.000250
0.000020	0.000020	
0.000002	0.000002	0.094846
0.000414	0.000414	0.0948 ohm
0.094596	0.025596	
0.0946 ohm	0.0256 ohm	

(1 to B) + (B to E) = 0.0948
(2 to E) 0.0256
0.1204 } 0.0202 ohm

a, b, c / $a+b$

This value of 0.0202 ohm is obtained from equation

$$c = \frac{a+b}{ab}$$

where

c = combined value of two reactances in parallel

a and b = the separate parallel reactances

1 and 2 through E-J-H-L to A

0.020200
0.000250
0.001880
0.001880
0.000390
0.000008
0.000652
0.025260

0.000250 } ..... E to L
0.001880 }
0.000390 }
0.000008 } ..... L to A
0.000652 }

0.0253 ohm from generator

Reactances of transformer and generators only = transformer + utility system ... 0.0149 ohm

generators 0.0920
0.0230 } ..... 0.0184 ohm
0.1150

Short-circuit amperes = volts to neutral / reactance = $\frac{277}{X}$

Short-circuit amperes from generator number 1 ..... 277/0.0946 = 2,940
Short-circuit amperes from generator number 2 and utility system ..... 277/0.0115 = 24,100
Total 27,040

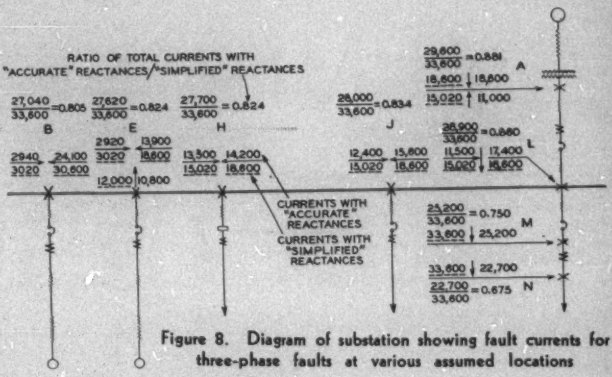


Figure 8. Diagram of substation showing fault currents for three-phase faults at various assumed locations

	Short-Circuit Amperes			
	Complete Reactances		Simplified Reactances*	
	Ohms	Amp	Ohms	Amp
From utility system	0.0149	18,600	0.0149	18,600
From generators	0.0253	11,000	0.0184	15,020
Total		29,600		33,620

* By "simplified reactances" is meant the use of transformer and generator reactances only; the effects of buses, air breakers, current transformers, leads, etc. is neglected.

Fault at (B)

Utility system to L to E:

0.008000
0.006900
0.000652
0.000008
0
0.000390
0.001880
0.001880
0.000250
0.019960 = 0.0200 } 0.0112 ohm, combined from utility system
2 to E 0.0256 } and generator number 2 to E
Total 0.0456 }

0.00025 E to B
0.01145 ohm to B

With simplified reactances

	Ohms	Amperes
From generator number 1	0.0920	3,020
From generator number 2	0.0230	12,000 } 30,600
From utility system	0.0149	18,600 }
Total		33,620

Fault at (E)

	Ohms	Amperes
1 to B to E (from calculations for A)	0.0948	2,920
2 to E	0.0256	10,800
Utility system to L to E		
Totaled under "Fault at (B)"	0.01996	13,900
		27,620
Simplified reactances:		
generator number 1	0.0920	3,020
generator number 2	0.0230	12,000
utility system	0.0149	18,600
Total		33,620

Fault at (H)

	Ohms	Amperes
1 to B to E 0.0948		
2 to E 0.0256 } 0.0202		
0.1204		
E to H 0.00025		
	0.02045	0.02045 ... 13,500
	0.01996	
	−0.00025	
	0.01970	0.0197 ... 14,200
		27,700

By simplified reactances, as before, total = 33,620

Fault at (J)

		Ohms	Amperes
1 and 2 to E	0.02020		
	0.00025		
E to H to J	0.00188		
	0.02233	0.0223	12,400
Utility system to L to J	0.008000		
	0.006900		
	0.000652		
	0.000008		
	0.000390		
	0.015950		
	0.001880		
	0.017830	0.0178	15,600
			28,000

Fault at (L)

1 and 2 to E	0.02020		
	0.00025		
	0.00188		
	0.00188		
1 and 2 to L	0.02421	0.0242	11,500
Utility system to L	0.01595	0.01595	17,400
			28,900

Fault at (M)

Total reactance to L = 0.009600 ohm

0.02410
0.01595 } 0.0096 ohm
0.04005

L to M	0.000414	
	0.001000	
Total reactance to M		0.011014 ohm

Total amperes at $M = 277/0.0110 = 25,200$

Fault at (N)

Total reactance to M	0.0110
M to N	0.0012
	0.0122

Total amperes at $N = 277/0.0122 = 22,700$

References

1. Calculation of Short-Circuit Currents in A-C Networks. W. M. Hanna, *General Electric Review*, 1937.

2. Relay Handbook Supplement, National Electric Light Association, 1931.

3. Electrical Characteristics of Transmission Circuits. William Nesbit.

4. Impedance of Three-Phase Secondary Mains in Nonmetallic and Iron Conduits. L. Brieger, Edison Electric Institute *Bulletin*, February 1938.

Illumination Note

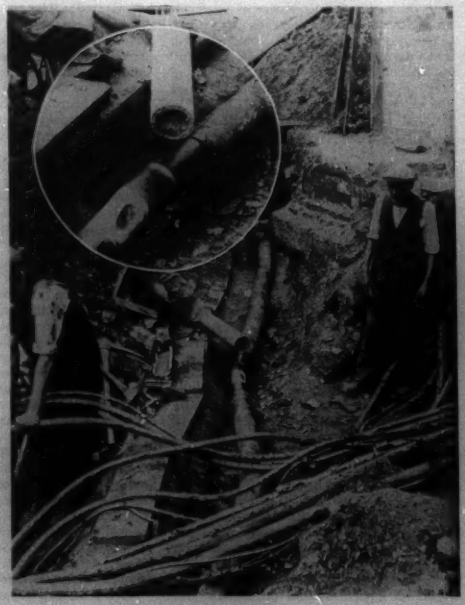
Flowing and Brilliant. California's well-known pride in her sons displays itself in a novel and spectacular manner by the illuminated cascade and fountain installed in the Joaquin Miller Park in Oakland and dedicated to California writers.

Jets, cascades, spray, and pools, supplied with about 1,000 gallons of water per minute, are illuminated in changing color by various combinations of floodlights and underwater lighting units. Control of the water flow and of the color and brilliance of the lights is electrical and automatic, with a normal cycle of about nine minutes, but of adjustable duration.

Compression Cable Withstands Bombing

WHAT happened to a Hochstadter compression-type cable in London, England, when an aerial bomb struck nearby may be seen from the accompanying illustration. Other than being forced slightly out of its original position and the enclosing pipe being dented in one place, the cable was not damaged and continued in service without interruption. The inset shows a closeup at the point where the cable enclosure was dented, the corrosion-protective covering having been removed over a short length. Adjacent cables were put out of commission, leaving the compression cable to carry the entire load for the areas it serves, and other underground structures were badly damaged. The bombing occurred near the point where the cable enters the substation.

This is said to be the first cable of its type; it was installed in London in 1932 and has been in continuous service since. It is a three-conductor 66-kv cable, and is enclosed in a five-inch steel pipe having a wall thickness of 0.167 inch, which is filled with gas at a pressure of 200 pounds per square inch.



Contributed for the AIEE committee on production and application of light by L. A. Hawkins (A'03, M'13) executive engineer, research laboratory, General Electric Company, Schenectady, N. Y.

Institute Activities

Production—the Engineers' Defense Job

A Message From President Sorensen

THE PRESIDENT of the United States, according to the daily press, has declared there is need for still greater acceleration in the manufacture of machines and other defense requirements and that it may become necessary if that need is to be satisfied to withdraw from military service some of the engineers and others with specialized skills now engaged therein and assign them to work in factories making defense equipment.

President James Bryant Conant of Harvard University and others, who have recently been in England as special delegates from the United States, and have witnessed the actual conditions under which the English are waging their battle for democratic freedom, have observed the heartbreaking shortage of engineers, and have come to a full realization of the fact that mechanized war demands a very large number of engineers and skilled technicians for the design and manufacture of mechanical devices and the munitions used by them. The use of men with mechanical and engineering ability for any work other than the making of machinery seems at this time to be very unwise and even unpatriotic.

This issue of ELECTRICAL ENGINEERING contains an address, "Priorities in Men" by Doctor Harvey N. Davis, president of Stevens Institute of Technology, which was delivered May 2 at the AIEE Northeastern District Meeting in Rochester, N. Y. President Davis' address should be given careful study by manufacturing companies, selective service boards, college faculties, and all engineers.

As president of the AIEE I have been asked to comment regarding engineers and selective service. I am much interested in accepting the invitation, because I am wholeheartedly of the opinion that every engineer in training (which includes men in college and known to be ready for graduation at a certain time) or engaged in engineering service can for the time being best contribute to the production of defense paraphernalia for his country by continuing his established engineering program. Furthermore, I am of the opinion that the American Council on Education and those persons in Washington who are in charge of the national selective service system are in agreement with the thought that for the present "selective service" means that every engineer engaged in production engineering of any sort, as well as those in training for that production, should be kept at their work until conditions now prevailing have been changed by production having attained a pace which will, with safety to our defense program, permit the release of engineers from production jobs to what may be called operation occupations, one of which is military service as commonly understood.

Such a procedure does not indicate on the part of engineers any desire to avoid military service when that service is needed. Indeed the program of keeping engineers on production logically may be the best program for preparing these same men to render, when the time comes, the most effective kind of military service inherent in a mechanized military program. This is possible because men who have designed and made machines have a knowledge of how those machines should be operated that cannot be attained by any other experience.

The deferment of military service for engineers and their use at the vital defense business of manufacturing until the manufacturing program has reached a desired speed can be carried out without any change in the present selective service laws and without any onus being attached to the activities of engineers and technical men whose time for military service is deferred until the manufacturing bottleneck has been eliminated. The two essential features in such a program are the development of an understanding among our citizens of the critical need for engineers and technicians, and a complete mutual understanding and unanimous co-operation among selective service boards, manufacturing establishments, colleges, and the individuals involved.

Every factory today should be supporting the defense program by being engaged in making goods directly or indirectly applicable to the defense program. Those industries making goods directly applicable to the program should keep on the job every day every possible man whose leaving the job slows down or curtails the production of needed equipment for even as little as a few hours, because time is the essence of the program and every hour lost is gone forever and may prove very costly. Every engineer and skilled craftsman should be at one of these jobs. If he is not engaged in doing such a job, he should change his occupation to a defense productive job as soon as possible.

Every man who contemplates such a change, which includes every senior student, junior student, and graduate student in an engineering college who has a satisfactory record of achievement in his work and who will graduate as scheduled with his class, should be held to his program of preparation until it has been completed and should be allowed a reasonable time after graduation to obtain employment at some occupation where his training will be applicable to the defense program.

Every industry making defense equipment, therefore, whenever the enlistment for military service of one of their men doing good work in manufacturing comes up for consideration, should present to the selective service boards all the facts pertaining to the usefulness of the man in the manufacturing program.

Likewise, every engineering college, when a teacher or student is called by the selective service board, should supply the local selective service board with complete information regarding the man's status as teacher or student and argue fully as to his effectiveness and the need of his particular service in the program of training engineers and technical men.

In conjunction with the information presented by the industry or engineering college every individual engaged in defense production should, when called to report, file with his selective service board complete and accurate data regarding his work, including the time required to have a successor ready to carry on his work.

All this procedure is necessary and should not be considered as an attempt to avoid military service in any way. Quite the contrary, for in our mechanized military program of today such procedure is just a way of determining how every man may be kept where he can be of greatest service to the defense program. This idea naturally is not one readily conceived by many persons, because in all wars preceding the present one, battle strength has been determined to a much greater degree by the mere number of fighting soldiers available and the completeness of their training for marching and for hand-to-hand combat. In the present war the effectiveness of fighting forces is determined not by the gross number of men, but by the number and quality of machines available and the skill of a comparatively few men highly trained in the knowledge of how these machines are made and effectively operated. As has been said in this war the job at the traditional battle front seems to be for the few and the vital production job behind the line for the many. While this condition exists, we cannot afford to have any more men doing what some engineers in service are now doing: work routine such as issuing equipment to recruits.

In conclusion, therefore, while the need is for manufacture rather than for fighters, may I urge that industry, selective service boards, engineering-college faculties, and engineers in practice or in training, all co-operate to make production reach the desired goal, until such time as the need for technical ability in fighting forces begins to catch up with the demand for manufacturing ability. At which time, I am sure, every engineer will be more than willing to change from the job of manufacturing mechanisms of war to the job of operating these devices, and this they will do with a skill that would not be theirs had they not had the experience that is acquired in the factory.

1941 Summer Convention Program Completed

ALL arrangements have been completed for the AIEE summer convention to be held in Toronto, Canada, June 16–20, 1941, with headquarters in the Royal York Hotel. The business features of the convention will consist of ten technical sessions, five technical conferences, and one general session, in addition to the annual meeting, two sections of the conference of officers, delegates, and members, and the Branch counselors' conference. The summer convention committee, under the chairmanship of M. J. McHenry, has arranged an excellent series of social and recreational features beginning with an English tea party at 4:15 p.m. on Sunday, June 15. An account of these features, together with a schedule of events, was given in the May issue, pages 226–9. An additional inspection trip to view the highway lighting on the Queen Elizabeth Way has been added to the list already given.

H. COONLEY TO ADDRESS GENERAL SESSION

For this meeting of the AIEE in Canada, the program committee has selected as the theme of the general session the broad and all-important topic of co-operative effort in the support and further development of our system of free enterprise. This topic will be ably presented by Howard Coonley, chairman of the board of the Walworth Company and chairman of the advisory committee of the American Standards Association. AIEE members have occasion to remember well the stirring address "Total Security—a Challenge" delivered at the recent AIEE winter convention in Philadelphia and published in the March issue of ELECTRICAL ENGINEERING. Mr. Coonley's message at Toronto is expected to stress further the importance of every intelligent individual giving serious consideration to these vital topics of the day, and undoubtedly Mr. Coonley will inspire engineers to a more active and effective participation in, and will give many practical suggestions toward, the solution of the more significant problems facing democracy.

ROUTES TO TORONTO

For the summer convention, "all roads lead to Toronto," with excellent facilities for air, rail, or water travel, and excellent highways for automobile travel. From essentially all directions, travel to Toronto is easy. In most instances economical summer round-trip rates will be in force.

For those traveling from or through New York City or New England a special round-trip combination of steamer and train service is offered through the collaboration of the New York Central Railroad and the Canada Steamship Lines. The cost of this combined trip to Toronto, Montreal, and return, including Pullman accommodations on the train and meals and berth on the steamer, is quoted as $45.15 from New York City; $41.80 from Schenectady; and $49.30 from Boston. Canada Steamship Lines' steamers leave Toronto at 3 p.m. eastern standard time on Mondays, Wednesdays, and Saturdays for the trip across the length of Lake Ontario and through the Thousand Islands and the rapids of the St. Lawrence River, arriving at Montreal at 6:30 a.m.

Attention is called to the famous Saguenay River trip from Montreal, of three nights and two days duration. The all-expense cost, including meals and berth, is $38.00. Stopovers may be made at any point en route, such as Murray Bay or Tadoussac, or at Quebec.

The all-rail direct round trip from New York City to Toronto is quoted at $35.90 including Pullman lower berth but no meals. Trains providing through facilities leave New York at 9 a.m., 8:15 p.m., and 11:35 p.m., arriving at Toronto respectively at 8:20 p.m., 8 a.m., and 11:30 a.m.

Further information may be secured from J. P. Sweeney, New York Central Railroad, 466 Lexington Avenue, New York, N. Y.; or from J. J. Daly, Canada Steamship Lines, 535 Fifth Avenue, New York, N. Y.

ADVANCE REGISTRATION

Members who have received an advance registration card should fill in and return the card promptly, if they have not already done so. Hotel reservations should be made by writing directly to the Royal York Hotel, Toronto, Canada, or any other hotel preferred. For convenience, the rates of the Royal York and several other hotels were given in the May issue, page 229. The rate for a double room for two persons at the Royal York, incorrectly stated there as $6.00, is $7.00. For technical program see pages 282–3.

Howard Coonley to Address Summer Convention

Taking as his theme the need for strong and co-operative effort to insure the survival of the free-enterprise system and the democratic way of life, Howard Coonley, chairman of the board of the Walworth Company, New York, N. Y., will be the featured speaker at the general session, Thursday morning, June 19, of the AIEE 1941 summer convention at Toronto, Can.

Mr. Coonley is chairman of the advisory committee of the American Standards Association, a past president of that or-

HOWARD COONLEY

ganization, and past president, past chairman of the board, and currently chairman of the executive committee of the National Association of Manufacturers. A native (1876) of Chicago, Ill., he received his first business experience from 1900 to 1902 with the Chicago office of the Walter G. Baker Company. In 1902 he and his three brothers organized the Coonley Manufacturing Company, Cicero, Ill., to make enamel cooking utensils, of which he was vice-president 1902–08, and president 1908–30. He was also associated with his brothers in a pioneering enterprise in Texas in the early 1900s, which included development of cattle raising and farming and ultimately building several towns and a 40-mile railroad on a 100,000-acre tract.

In 1913 he became president of the Walworth Company, maker of valves, pipe fittings, and tools, and in 1936 became chairman of the board. For many years he has taken an active interest in improving the company's industrial relations and in promoting the safety, health, and welfare of its employees. He is a member of the American Society of Mechanical Engineers and of the Academy of Arts and Sciences.

Speakers Stress National Defense at North Eastern District Meeting

CONTINUING its traditional practice of giving prominent attention to the non-technical as well as the technical phases of engineering enterprise, the AIEE North Eastern District featured a generous number of speakers on topics of general interest and importance during its recent Rochester meeting. The all-important all-pervading subject of national defense, in various aspects, furnished pretty much of a common theme for the various addresses.

The list of prominent speakers included Doctor Harvey N. Davis, president of Stevens Institute of Technology; Doctor Alan Valentine, president of the University of Rochester; Doctor R. H. Manson, vice-president and general manager, Stromberg-Carlson Telephone Manufacturing Company; Herman Russell, president, Rochester Gas and Electric Corporation; Doctor R. W. Sorensen, president AIEE; Everett S. Lee, vice-president AIEE, North Eastern District; and National Secretary H. H. Henline.

"Priorities in Men" was the topic to which Doctor Davis spoke in emphasizing what he termed as a defense necessity and patriotic duty of all parties concerned of conserving and allocating technically trained man power just as carefully and as intelligently as strategic inanimate materials are allocated under the priorities system. The

full text of Doctor Davis' address appears elsewhere in this issue. Doctor Sorensen, in remarks made upon various occasions, touched upon this as well as other matters of interest and significance to the Institute. In general, Doctor Sorensen's remarks are embraced by a written contribution which appears elsewhere in this issue, the third in a series of recent "Messages From the President" in which he has discussed topics relating to national defense.

In discussing "The Engineering Societies and National Defense," Mr. Henline briefly reviewed the scope and nature of the AIEE and of the national societies of civil, mining, and mechanical engineers, indicating some of the differences in principal interests and objectives. Touching upon co-operative activities, Mr. Henline mentioned briefly the national census of engineerng firms, the national roster of engineering and scientific personnel, the selection of co-ordinators for the Defense Contracts Service, the study of supply and demand of engineers, and the National Technological Civil Protection Committee. He pointed out that in addition to collaborating on matters of direct common interest such as the foregoing, each of the four societies are carrying on other activities best suited to the membership of the individual organi-

Analysis of Registration at Rochester

Classification	Rochester Section	District 1*	Other Districts	Totals
Members	57	75	25	157
Enrolled Students	0	113	4	117
Men guests	27	25	8	60
Women guests	11	8	2	21
Totals	95	221	39	355

*Outside Rochester

North Eastern District Meeting Attendance 1931–1941

Date	Location	Attendance
1941—Apr. 30–May 2	Rochester, N. Y.	355
1939—May 3–5	Springfield, Mass.	439
1938—May 18–20	Lenox, Mass.	439
1937—May 5–7	Buffalo, N. Y.	371
1936—May 6–8	New Haven, Conn.	338
1934—May 16–18	Worcester, Mass.	337
1933—May 10–12	Schenectady, N. Y.	451
1932—May 4–7	Providence, R. I.	252
1931—Apr. 29–May 2	Rochester, N. Y.	370

zations, with appropriate collaboration, but naturally not all of the four doing the same thing. He reviewed typical AIEE efforts to co-operate in the matter of national defense, including the resolution adopted by the board of directors last June offering the services and facilities of the Institute to the Government, the series of six radio programs broadcast toward the end of this last winter, the decision to form an AIEE committee on national defense, the important local work undertaken by many Sections, and the many important technological contributions stimulated and facilitated through the work of the Institute's various committees.

Summer Convention

(Eastern Daylight

● PAMPHLET reproductions of authors' manuscripts of the numbered papers listed in this program may be obtained as noted in the following paragraphs.

● ABSTRACTS of papers appear on pages 290–3 of this issue and pages 230–1 of the May 1941 issue of Electrical Engineering.

● PRICES and instructions for securing advance copies of these papers accom-

Monday, June 16

9:00 a.m. Registration

9:30 a.m. Instruments and Measurements

41-106. Effect of Sapphire Crystal Orientation on the Wear of Watthour Meter Bearings. **J. H. Goss,** General Electric Company

41-108. An Improved Frequency Meter for Commercial Power Frequencies. **K. J. Knudsen,** Hickok Electrical Instrument Company

41-119. Power Circuit Instruments for the Higher Range of Audio-Frequencies. **L. J. Lunas** and **Paul MacGahan,** Westinghouse Electric and Manufacturing Company

41-125. Relative Accuracy of Three-Phase Metering Combinations. **C. T. Weller,** General Electric Company

41-112. The Shielding of Permanent Magnets From Transient Magnetic Fields. **G. J. Wey,** Westinghouse Electric and Manufacturing Company

9:30 a.m. Communication

41-113. Radio Broadcasting in Canada. **Augustin Frigon,** Canadian Broadcasting Corporation

41-129. The Measurement of Body Currents. **R. S. Schwab,** Massachusetts General Hospital

41-130-ACO.* Sound Recording for the Amateur. **A. L. Williams,** The Brush Development Company

41-111-ACO.* Phonograph Record Recording and Reproducing. **A. D. Burt,** RCA Manufacturing Company, Inc.

Wednesday, June 18

9:30 a.m. Basic Sciences and Electronics

41-103. A Short Method for Evaluating Determinants and Solving Systems of Linear Equations With Real or Complex Coefficients. **P. D. Crout,** Massachusetts Institute of Technology

41-105. Diode Rectifying Circuits With Capacitance Filters. **D. L. Waidelich,** University of Missouri

41-96. Measurement of Pre-breakdown Currents in Dielectrics With a Cathode-Ray Tube. **H. H. Race,** General Electric Company

41-107. Analytical Methods of Solving Discrete Nonlinear Problems in Electrical Engineering. **E. G. Keller,** Lockheed Aircraft Corporation

41-117. Current Rating With Life of Cold-Cathode Tubes. **G. H. Rockwood,** Bell Telephone Laboratories, Inc.

9:30 a.m. Insulation Testing

41-131. Impulse Strength as a Measure of Cable Quality. **L. I. Komives,** The Detroit Edison Company

41-118. The Basis for the Nondestructive Testing of Insulation. **R. F. Field,** General Radio Company

41-132. The A-C Dielectric-Loss and Power-Factor Method for Field Investigation of Electrical Insulation. **F. C. Doble,** Doble Engineering Company

41-120. Bushing Tests. **A. L. Brownlee** and **W. H. Wickham,** Commonwealth Edison Company

41-133. The Protection of Solid Insulation by Lightning Arresters. **D. D. MacCarthy** and **T. J. Carpenter,** General Electric Company

9:30 a.m. Switching Equipment

41-114. Mechanical Simplicity of Air-Blast Circuit Breakers. **H. W. Haberl,** Montreal Light, Heat, and Power, Consolidated, and **Otto Jensen,** I-T-E Circuit Breaker Company

41-121. System Short-Circuit Currents. **W. M. Hanna,** Consolidated Gas, Electric Light, and Power Company, **H. A. Travers** and **C. F. Wagner,** Westinghouse Electric and Manufacturing Company, and **C. A. Woodrow** and **W. F. Skeats,** General Electric Company

41-116. Power Circuit Breaker Ratings. **R. C. Van Sickle,** Westinghouse Electric and Manufacturing Company

41-128. Protection of Low-Voltage Circuits by Air Circuit Breakers in Cascade Arrangement. **A. E. Anderson** and **C. H. Black,** General Electric Company

41-134. Dielectric Strength of Oil for High-Potential Testing of Oil Circuit Breakers. **H. J. Lingal,** Westinghouse Electric and Manufacturing Company, **W. F. Skeats,** General Electric Company, and **H. D. Braley,** Consolidated Edison Company of New York, Inc.

2:00 p.m. Electrical Machinery

41-84. Methods of Determining Natural Frequencies in Coils and Windings. **L. V. Bewley,** Lehigh University, and **J. H. Hagenguth** and **F. R. Jackson, Jr.,** General Electric Company

41-110. Damping and Synchronizing Torque of the Double-Fed Asynchronous Machine. **M. M. Liwschitz,** Westinghouse Electric and Manufacturing Company

41-126. Transient Torques in Squirrel-Cage Induction Motors, With Special Reference to Plugging. **E. S. Gilfillan, Jr.,** and **Edward Kaplan,** Westinghouse Electric and Manufacturing Company

41-127. Excitation Circuits for Ignitron Rectifiers. **H. C. Myers** and **J. H. Cox,** Westinghouse Electric and Manufacturing Company

41-124. A New Transformer for Base Load Stations. **Philip Sporn,** American Gas and Electric Service Corporation, and **H. V. Putman,** Westinghouse Electric and Manufacturing Company

2:00 p.m. Relays and Bus Protection

41-99. Bus Protection Independent of Current Transformer Characteristics. **G. Steeb,** Buffalo, Niagara, and Eastern Power Corporation

41-135. New Current Transformers for Bus Differential Protection. **L. F. Kennedy** and **A. T. Sinks,** General Electric Company

Vice-President Lee spoke upon several occasions, introducing many a thought of inspiration and challenge. In his address of welcome, Mr. Lee emphasized the multiple capacity in which AIEE members were present for the Rochester meeting: as representatives of the 2,300 members of the North Eastern District with its 12 Sections and 18 Student Branches; as representatives of the AIEE's world membership of some 18,000; as representatives of "a million or more" engineers and scientists;

Technical Program

Saving Time)

pany the abstracts. Mail orders are advisable, particularly from out-of-town members, as an adequate supply of each paper at the convention cannot be assured. Only numbered papers are available in pamphlet form.

● ALL PAPERS regularly approved by the technical program committee ultimately will be published in Transactions; many will appear also in Electrical Engineering.

41-109. A Simple Method for Determination of Ratio Error and Phase Angle in Current Transformers. **E. C. Wentz,** Westinghouse Electric and Manufacturing Company

41-122. D-C Machine Flashover and Bus Short-Circuit Protection. **T. B. Montgomery and J. F. Sellers,** Allis-Chalmers Manufacturing Company

41-102. Development in Lightning Protection of Stations. **E. R. Whitehead,** Duquesne Light Company

2:00 p.m. Conference on Industrial High-Frequency Heating by Means of Electronic Tubes

Heating by means of high-frequency currents has been an industrial process for a number of years. Alternating-current generators or some form of spark gap with an oscillating circuit have been used as converting devices. More recently two factors have served to make the use of electron tubes a more promising method than heretofore: first, the use of very high frequencies (megacycles) to give heating of material between capacitor plates due to dielectric losses; and second, a combination of higher power requirements than obtainable from a spark-gap type of converter in combination with a higher frequency than is practical from an alternator. It is hoped that those interested in the use of high-frequency heating, as well as those interested in the design of the equipment, will attend this conference.

Discussion leader: **W. C. White,** General Electric Company.

Thursday, June 19

10:00 a.m. General Session

President R. W. Sorensen, presiding
Address, "Co-operative Effort in Support of Our System of Free Enterprise." Howard Coonley, chairman of the board, Walworth Company, Inc.

2:00 p.m. Power Transmission

41-95. The 220,000-Volt System of the Hydro-Electric Power Commission of Ontario—II. **A. H. Frampton and E. M. Wood,** Hydro-Electric Power Commission of Ontario

41-94. Conductor Vibration—The Theory of Torsional Dampers. **J. W. Speight,** Hydro-Electric Power Commission of Ontario

41-97. Measurement and Control of Conductor Vibration. **G. B. Tebo,** The Hydro-Electric Power Commission of Ontario

41-115. Lightning to the Empire State Building—II. **K. B. McEachron,** General Electric Company

41-137. Field Investigations of Lightning. **C. F. Wagner, G. D. McCann,** and **Edward Beck,** Westinghouse Electric and Manufacturing Company

2:00 p.m. Industrial Power Applications

41-123. The Incandescent Lamp Situation from the Engineering Point of View. **P. S. Millar,** Electrical Testing Laboratories

41-136. A Distribution System for War-Time Plant Expansion. **J. L. McKeever,** Canadian General Electric Company, Ltd.

41-98. A New Mercury Rheostatic Element for Regulation and Control. **K. A. Oplinger,** Westinghouse Electric and Manufacturing Company

2:00 p.m. Conference on Education

Friday, June 20

9:30 a.m. Land Transportation

41-101. Electric Locomotive Application. **E. W. Brandenstein**** and **D. R. MacLeod,** General Electric Company

41-100. Glass Bulb Mercury-Arc Rectifiers for Traction Service. **C. E. Woolgar,** Northern Electric Company

41-104. Modern Motors Serve City Transit Systems. **W. J. Clardy** and **C. A. Atwell,** Westinghouse Electric and Manufacturing Company

9:30 a.m. Conference on Power Generation

This conference will continue the work of the January meeting on load swings, governing, system stability, and service continuity.

CP.† A Turbine Governor Performance Analyzer. **W. O. Osbon,** Westinghouse Electric and Manufacturing Company

CP.† Synthetic or Equivalent Load-Curves. **R. F. Hamilton,** Consulting Engineer

9:30 a.m. Conference on Protective Lighting

This conference will consider the protective lighting of factories against sabotage and espionage. The equipment for use, the distribution systems, and various sundry types of protective lighting will be discussed as well as black-out lighting as practiced in countries now at war from the point of view of possible future application.

2:00 p.m. Conference on Domestic and Commercial Applications

Brief summaries of work on the following topics in this field will be presented: motor-actuated appliances, heat-actuated appliances, interior wiring, and service requirements for industrial and commercial applications.

CP.† Controlling Domestic Washing Machines Automatically. **W. J. Russell,** Westinghouse Electric and Manufacturing Company
CP.† Domestic Oil Burner Controls. **W. H. DeLancey,** Gilbert and Barker Manufacturing Company

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*ACO: Advance copies only available; not intended for publication in Transactions.

†CP: Conference paper; no advance copies are available; not intended for publication in Transactions.

**Deceased May 20, 1941.

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as citizens with responsibilities paralleling their technical and professional enterprises and at least equally important.

Doctor Valentine, in a challenging address delivered before the entire assemblage at the banquet, urged engineers to endeavor to "help the people of the country to make the difficult discrimination between facts and opinions in the dangerous and difficult circumstances which so seriously threaten our security as a nation and our liberty as individuals." Doctor Valentine emphasized that a thoughtful and educated people, especially in an emergency such as the present, should discourage passion and name-calling; should encourage tolerance, especially with reference to minor or technical differences; should carefully distinguish between facts and opinions; should ever be on the alert to guard and preserve the Bill of Rights; should now "before the heat of battle" thoughtfully consider the kind of peace to be sought for and the desirable objectives and terms to be associated with it toward a constructive and durable result—citing a rapid and preconsidered peace is necessary if the hatreds and conflicting interests are not to be fanned anew by over-long negotiations.

Doctor Manson, in a necessarily limited way, indicated something of the significant contributions being made to national defense by the communications industry.

ATTENDANCE

The meeting of the North Eastern District in Rochester, N. Y., April 30–May 2, was the 15th such meeting to be held by the District and the second to be held in Rochester. The accompanying tables present an analysis of the attendance of this year's meeting and a comparison with recent part years.

STUDENT ACTIVITIES

Continuing the tradition of the North Eastern District, student activities were given a prominent place on the meeting program, including two student technical sessions and joint participation in many of the general activities and inspection trips. Of the 18 Student Branches in the North Eastern District, all but one were represented, many by relatively large groups. It was reported that in terms of round-trip traveled distances, the students present at Rochester represented about 80,000 man-miles of travel.

At a brief business session held immediately following a general luncheon, Professor Eric A. Walker, chairman of the North Eastern District committee on student activities was appointed to serve as the District's official counselor-delegate to the annual conference of officers, delegates, and members to be held as a part of the program for the forthcoming summer convention at Toronto.

The student technical sessions were arranged as follows:

Graduate Session

Peter Jaremko presiding.

The Beam Power Oscillator. **H. L. Kraus,** Yale University.

A Highly Sensitive D-C Amplifier Using A-C Power Exclusively. **S. E. Miller,** Massachusetts Institute of Technology.

Transients in Small Synchronous Machines. **Frank S. White Jr.,** Harvard University.

Impedance Matching of Directional Antenna Arrays. **C. W. Thulin,** Worcester Polytechnic Institute.

A New Transmitting Antenna for High-Definition Television. **Burton P. Brown Jr.,** University of Vermont.

Undergraduate Communications Session

H. L. Kraus presiding.

A High Impedance Voltage Indicator. **Leon E. Coff Jr.,** and **James F. Hasney,** Rhode Island State College.

The Ionosphere and Its Effect on Radio Waves. **S. K. Brown,** Cornell University.

Development of an Acoustical Resistance.

A. S. Chodakowski and **F. W. Ziegler**, Worcester Polytechnic Institute.

AN ELECTRONIC HALF-CYCLE COUNTER. **B. E. Hand**, Massachusetts Institute of Technology.

DEVELOPMENT OF A HIGH-SPEED WATT-SECOND RECORDER FOR MEASUREMENT OF TRANSIENT ENERGIES. **J. H. Arthur**, Rensselaer Polytechnic Institute.

UNIVERSAL-FREQUENCY SWEEP CIRCUIT. **W. A Knoop, Jr.**, Rensselaer Polytechnic Institute.

Undergraduate Power Session

J. Coolidge presiding

SOME PROBLEMS IN SECONDARY GROUNDING. **Arthur Eckels**, University of Connecticut.

ECONOMICS OF CABLE TESTING. **Stephen J. O'Neil**, Northeastern University.

EFFECT OF THE SHAPE OF ELECTRODES ON THE BREAKDOWN VOLTAGE OF A STANDARD INSULATOR. **Clayton H. Preble**, University of Maine.

ARTIFICIAL LOADING OF INDUCTION MACHINES BY UNBALANCED VOLTAGES. **R. A. Muir** and **G. T. Douglass**, Worcester Polytechnic Institute.

CHANGES IN DIELECTRIC CONSTANT OF ALKALI-HALIDE CRYSTALS UNDER THE INFLUENCE OF IRRADIATION. **Milton Sanders**, Massachusetts Institute of Technology.

Doctor Scott Challenges Students. Doctor Charles F. Scott, past president of the Institute and a founder of AIEE Student Branch activities, and long a regular attendant at these gatherings, found himself unable to attend and sent the following challenging message to be read at the student luncheon:

"To the AIEE Student Convention at Rochester:

"As your District member of the National Committee on Student Branches I send you greetings.

"Nearly 40 years ago Branches were formed for bringing to the student the experience of older engineers and the professional attitude and understanding which may aid him in his future career. The reason why the Institute became interested in the development of men as well as technical matters was the rapid growth of the electrical industry and the increasing demand for competent engineers. The coming need of competent men is greater now than then.

"Just how can you make your Branch serve you in preparing you for your future career? I say how can *you* do this; not your counselor, or remote committees or Institute officers, but *you*, you students?

"The Branch is peculiarly your own affair. Curricula and schedules are prescribed; you follow orders. But the Branch is yours to do with what you want to do. It gives opportunity for collective action; action nowadays is by groups and organizations; your technical programs may have their most fruitful results—their by-products—in orderly composition, in effective presentation, in thinking on your feet, in keen discussion and in the handling of a meeting. Student conventions in the Southern District (where 17 institutions were represented last month) and in the Middle Eastern District (the January meeting in Pittsburgh) as well as in our own District, have convinced me of the high quality students are attaining. But nearly all papers are technical. Yet engineers must be more than technical. In the corridor of Dunham Laboratory at Yale are these words by an engineer, a soldier, an editor, and an industrial executive.

"Engineers reach the limit of their usefulness from defects of character rather than from want of technical attainments. Our greatest difficulty is to find courage, candor, imagination, large vision, and high ambition.

"Confirmatory is the result of a questionnaire responded to by many engineers which evaluates the qualities of the successful engineer as 25 per cent technical knowledge and skill and 75 per cent qualities listed by Colonel Prout. Now the 25 per cent is the concern of curriculum and professors' grades. The 75 per cent are personal qualities which it is your responsibility to develop. Are these matters simple and clear? What is their significance? If so much depends on nontechnical qualities why is this not a field for exploration by your Branch?

"Again, many of you are looking forward to belonging to the engineering profession. Just what does this imply? What is the difference between the engineering profession and technical employment? Should not your Branch become interested in the history, the present status, and the development of the engineering profession? How will professional organizations and codes of ethics and legal registration affect you?

"There are printed articles that may form a fruitful basis for your discussions. I want to urge your initiative and independent activity in exploring some of the nontechnical phases of engineering—those which may lead you to higher achievement and success.

"At the recent convention of the Southern District held at the University of Alabama it was voted that Branches should devote at least one meeting a year to professional topics and that papers for prizes be in two groups, one technical and one nontechnical."

DISTRICT EXECUTIVE COMMITTEE MEETING

The executive committee of the North Eastern District held a luncheon conference and business meeting at which various matters of business and plans for future activities were discussed. Action was taken establishing August 1 as the closing date for the submission of student papers for District prize awards for the preceding academic year.

The North Eastern District meeting and Student Branch convention for 1942 is scheduled to be held in Schenectady, N. Y.

This meeting was attended by the following delegates:

Everett S. Lee, vice-president, AIEE
R. G. Lorraine, secretary, North Eastern District
Eric A. Walker, chairman, District committee on student activities
Robert W. Adams, chairman, Boston Section
L. I. Albert, chairman, Tufts College Branch
H. A. Baines, chairman, Providence Section
E. A. Gruppe, chairman, Syracuse Section
M. G. Northrop, chairman, Ithaca Section
O. E. Sawyer, secretary, Providence Section
J. P. Wood, secertary, Ithaca Section
T. T. Woodson, secretary, Schenectady Section

Also in attendance at the meeting were President R. W. Sorensen, H. H. Henline, national secretary, New York, F. N. Tompkins, ex-chairman of Providence Section, Ex-Vice-President C. L. Dawes, Program Chairman E. B. Alexander of the Niagara Frontier Section, V. Siegfried, vice-chairman of the membership committee, G. W. Dunlap, delegate for Schenectady Section, W. K. Parks, secretary of Niagara Frontier Section, W. F. Cotter, chairman of the Rochester Section, G. W. Eighmy, chairman of the Niagara Frontier Section, and W. Irving Middleton, secretary of the Boston Section.

PRIZES AWARDED

Prizes awarded at Rochester to authors of technical papers included the following:

1. District prize for 1939–40 for initial paper—to H. R. Mesh1, P. C. Michel, M. W. Sheldorf and T. M. Dickinson, for their paper "Measurements at Radio Frequencies," presented at the 1940 summer convention.

2. District prize for 1939–40 for best paper—to W. Mikelson and H. W. Bousman for their paper "Rapid-Recording A-C Bridge," presented at the 1940 summer convention.

3. District prize for 1939–40 for the best Student Branch paper—to T. F. C. Muchmore for his paper "A Study of Fluorescent Lamps" presented at the North Eastern District Student Convention, May 1940.

4. District honorable mention for Student Branch paper for 1939–40—to H. T. Marcy of Massachusetts Institute of Technology, Cambridge, for his paper "Measurement of Quadrature Synchronous Reactance Using Negative Excitation."

In addition to the foregoing more formal awards, the District maintained its tradition by making the following awards to enrolled students on the basis of the oral presentation of their papers at the Rochester meeting:

First prize, graduate session, to Burton P. Brown, Jr.

First prize, undergraduate communications session, to W. A. Knoop, Jr.

Second prize, undergraduate communications session, to A. W. Chodakowski and F. W. Ziegler

First prize, undergraduate power session, R. A. Muir and G. T. Douglass

Second prize, undergraduate power session, Stephen J. O'Neil

TECHNICAL SESSIONS

With the exception of the following two items subsequently added, the content of the technical program was in accordance with that published on page 177 of the recent April issue of ELECTRICAL ENGINEERING:

DP. Secondary Networks for Supplying Power Plant Auxiliaries, H. G. Barnett, Westinghouse Electric and Manufacturing Company.

DP. Carrier-Current Relay Equipment and Its Other Uses, S. L. Goldsborough, Westinghouse Electric and Manufacturing Company.

With these additions the technical program at Rochester was made up of 10 regular technical-program papers destined for TRANSACTIONS publication, 4 informal technical papers, and 4 technical addresses. In addition to these, of course, there were the 16 student technical papers and the various addresses on nontechnical topics. Average attendance at the technical sessions was about 75 or 80. The only parallel sessions were two of the student sessions.

A variety of prearranged inspection trips was available through the co-operation of the Rochester Telephone Corporation, the University of Rochester Medical School and the Physics and Optical Laboratories, the Rochester Products Division of the General Motors Corporation, the Rochester Gas and Electric Corporation, the Eastman Kodak Company, and other organizations.

In addition to the annual District banquet, the social and entertainment features offered included a smoker for the men and a paralleling dinner-bridge party for the women, various sight-seeing trips, and a general luncheon for students and others.

Section and Branch Activities—Annual Report for 1940–41

THE following constitutes the annual report on Institute Section and Branch activities for the fiscal year which ended April 30, 1941. Similar information for three preceding fiscal years appeared in ELECTRICAL ENGINEERING for June 1940, pages 250–3; June 1939, pages 268–71; June 1938, pages 263–6.

Present members of the Sections committee and the committee on Student Branches, which supervise the two important divisions of Institute activities covered by this report, are:

Sections—M. S. Coover, *chairman*, W. B. Morton, *vice-chairman and secretary*, C. A. Faust, O. W. Holden, E. T. Mahood, R. M. Pflazgraff, H. H. Race, I. Melville Stein, J. M. Thomson, W. H. Timbie, and *ex-officio* the chairmen of all Sections of the Institute.

Student Branches—H. W. Bibber, *chairman*, S. S. Attwood, W. C. DuVall, E. A. Loew, A. Naeter, C. W. Ricker, Charles F. Scott, E. M. Strong, R. G. Warner, and *ex-officio* all student Branch counselors.

SECTION ACTIVITIES

Two new Sections were organized: Arizona, including the entire state, which had been within the territory of the Los Angeles Section, and South Bend, to which was assigned territory previously in the Chicago, Fort Wayne, and Michigan Sections. These made a total of 10 new Sections organized within the past four years.

On account of the extensive territories involved, the names of two Sections were changed: Charleston to West Virginia, and El Paso to New Mexico-West Texas.

President Sorensen visited a large number of Sections, and his address "Engineering Horizons, Limited", illustrated with many lantern slides, which was given in most cases, was received with unusual enthusiasm, as shown by the close attention of all audiences and a large number of complimentary comments received by the national secretary.

Two Sections reported no activity. Eight Sections held more than 15 meetings each, 9 held from 12 to 15, 38 held from 8 to 11, 10 held from 4 to 7, and 6 held from 1 to 3.

Doctor J. O. Perrine, assistant vice-president, American Telephone and Telegraph Company, addressed meetings of a considerable number of Sections with attendance as high as 3,230, and more than 1,000 at the majority of the meetings.

Fourteen Sections, which held a total of 132 Section meetings, also held 103 technical-group, committee, or other special meetings. The average attendance at 42 of these was at least 50 per cent of the average at the Section meetings, showing the continuing popularity of the more specialized meetings.

Many of the Sections held meetings devoted to national defense subjects. The Sections responded splendidly in supplying information needed in the Institute's cooperation with other societies in the census of engineering firms and the selection of ad-

Table I. Section Meetings Held During Last Three Fiscal Years

	Fiscal Year Ending April 30		
	1939	1940	1941
Number of Sections	67	70	72
Number of meetings held	635	701	703
Average number of meetings	9.5	10.0	9.8
Total attendance	85,692	91,949	92,554
Average attendance per meeting	135	131	132

Table II. Section Meetings Held During Year Ending April 30, 1941

Section	AIEE Members August 1939	AIEE Members August 1940	Meetings During Year Number	Meetings During Year Average Attendance	Meetings During Year Average Attendance as Per Cent of Membership, August 1940
Akron	75	85	7	74	87
Alabama	31	40	2	27	67
Arizona*			1	41	
Boston	414	415	8	168	40
Central Indiana	126	132	7	117	89
Chicago	733	769	6	198	26
Industrial group			3	114	
Power group			4	137	
Communication group			3	167	
Cincinnati	180	207	8	172	83
Cleveland	298	332	8	149	45
Technical group			6	82	
Columbus	95	92	11		
Connecticut	265	279	9	91	33
Denver	182	192	10	61	32
East Tennessee	118	132	10	46	35
Erie	65	57	10		
Florida	73	78	3	92	118
Fort Wayne	98	109	8	93	85
Georgia	104	109	6	90	83
Houston	139	141	10	234	166
Iowa	67	72	8	88	122
Ithaca	51	51	9		
Kansas City	125	148	9	166	112
Lehigh Valley	191	191	8		
Los Angeles	483	506	8	146	29
Louisville	56	61	10	36	59
Lynn	145	147	5	900	610
Inspection trips			4		
Technical lectures			5		
Local conventions			2		
Madison	65	67	8	87	130
Rock River Valley Subsection			6	40	
Mansfield	64	68	9	113	
Maryland	224	252	11	124	49
Memphis	61	72	10	45	63
Mexico	56	56			
Michigan	358	370	8	179	48
Round-table discussions			1		
Milwaukee	270	280	8	144	51
RSM meetings			1	200	
Minnesota	89	107	11	97	91
Power group			1	30	
Montana	39	36	6	127	128
Muscle Shoals	46	33	9	49	148
Nebraska	56	48	5	48	100
New Mexico-West Texas		47	9	37	79
New Orleans	97	123	8	58	48
New York	3,355	3,346	5	460	14
Communication group			3	123	
Basic Science group			6	137	
Power group			12	209	
Illumination group			2	173	
Transportation group			3	342	
Niagara Frontier	201	197	9	65	33
North Carolina	85	91	2	104	114
North Texas	140	170	10	511	300
Oklahoma City	120	117	10	299	256
Philadelphia	610	650	9	200	31
Pittsburgh	517	564	10	221	39
Technical meetings			2	126	
Pittsfield	178	192	8	778	405
Technical meetings			5		
Colloquium meetings			4	42	
Popular meetings for high-school students			5	800	
Portland	151	176	9	69	39
Communication committee			4	41	
Transmission and distribution committee			4	69	
Providence	91	99	8	64	65
Rochester	95	103	12	89	86
St. Louis	268	273	9	393	144
San Antonio	43	45	7	44	98
San Diego	30	36	9	29	81
San Francisco	486	507	12	129	25
Technical meetings			5	87	
Saskatchewan	21	15	6	8	53
Schenectady	403	434	10	113	26
Technical discussion meetings			3	173	
Seattle	153	164	10	82	50
Technical group			2	55	
Electronics group			1	80	
Sharon	86	105	9	133	127
South Bend**			3		
South Carolina		37	3	36	97
Spokane	62	81	12	39	48
Springfield	60	57	9	91	160
Syracuse	71	75	6	130	173
Toledo	78	71	11	101	142
Toronto	338	342	14	211	62
Tulsa	107	94	8	121	129
Urbana	77	76	6	175	230
Utah	76	76	12	52	68
Idaho technical committee			6	26	
Vancouver	107	97	11	42	43
Virginia	94	111			
Washington	332	370	14	138	37
Junior technical sessions			19	35	
West Virginia		48	5	37	77
Wichita	46	52	10	150	289
Worcester	58	63	8	58	92
Total	72	14,078	14,844		
Total number of meetings					703
Total attendance					92,554

* Organized March 22, 1941.

** Organized February 26, 1941.

Table III. Branch Meetings Held During Year Ending April 30, 1941

Branch	Meetings During Year: Number	Meetings During Year: Average Attendance	Number of Talks by Students: Approximate
Akron, University of	4	26	1
Alabama Polytechnic Institute	8	34	1
Alabama, University of	11	24	4
Alberta, University of	10	23	14
Arizona, University of	22	9	16
Arkansas, University of	15	22	16
British Columbia, University of	6	25	10
Brooklyn, Polytechnic Institute of			
Day division	15	64	2
Evening division	9	28	1
Brown University	2	48	
Bucknell University	4	12	
California Institute of Technology	15		3
California, University of	37	34	7
Carnegie Institute of Technology	29	50	20
Case School of Applied Science	4	27	2
Catholic University of America	2	27	
Cincinnati, University of	11	91	8
Clarkson College of Technology	3	14	
Clemson Agricultural College	13	38	18
Colorado State College	6	20	4
Colorado, University of	9	172	1
Columbia University	5	22	
Connecticut, University of*	3	68	
Cooper Union			
Day division	4	24	
Evening division	13	28	5
Cornell University	5	27	
Denver, University of	6	35	
Detroit, University of	7	72	1
Drexel Institute of Technology	10	16	3
Duke University	9	23	
Florida, University of	2	28	2
George Washington University	5	63	3
Georgia School of Technology	5	61	
Harvard University	6	28	5
Idaho, University of	11	25	2
Illinois Institute of Technology	14	46	4
Illinois, University of	9	168	
Iowa State College	10	114	
Iowa, University of	27	42	28
Johns Hopkins University	15	26	16
Kansas State College	12	178	3
Kansas, University of	8	38	2
Kentucky, University of	23	62	2
Lafayette College			
Lehigh University	6	48	1
Louisiana State University	8	23	2
Louisville, University of	2	19	1
Maine, University of	10	16	4
Manhattan College†	1		
Marquette University	8	25	2
Maryland, University of	7	24	7
Massachusetts Institute of Technology	3	42	
Michigan College of Mining and Technology	8	31	2
Michigan State College	12	32	
Michigan, University of	6	44	
Milwaukee School of Engineering	3	57	1
Minnesota, University of	11		3
Mississippi State College	5	32	1
Missouri School of Mines and Metallurgy	9	33	7
Missouri, University of	8	35	3
Montana State College	28	29	89
Nebraska, University of	18	50	12
Nevada, University of	12	23	3
Newark College of Engineering	10	40	5
New Hampshire, University of	6	22	1
New Mexico State College	13	15	12
New Mexico, University of	12	13	7
New York, College of the City of			
Day division	22	48	1
Evening division			
New York University			
Day division	4	26	
Evening division	9	16	
North Carolina State College	14	46	3
North Dakota Agricultural College	6	12	4
North Dakota, University of	12	16	3
Northeastern University	12	69	6
Northwestern University	7	37	1
Norwich University**	1	33	
Notre Dame, University of	8	33	2
Ohio Northern University	8	42	1
Ohio State University	13	36	8
Ohio University	7	15	1
Oklahoma A.&M. College	12	287	2
Oklahoma, University of	9	42	2
Oregon State College	12	59	8
Pennsylvania State College	6	185	
Pennsylvania, University of	4	70	6
Pittsburgh, University of	24	89	23
Porto Rico, University of	1	43	
Pratt Institute	13	47	4
Princeton University	1	17	
Purdue University	12	103	
Rensselaer Polytechnic Institute	6	46	
Rhode Island State College	11	24	
Rice Institute	13	36	4
Rose Polytechnic Institute	6	23	3
Rutgers University	5	22	3
Santa Clara, University of	11	18	8
South Carolina, University of	3	23	
South Dakota State College	17	17	8
South Dakota State School of Mines	7	16	
Southern California, University of	14	28	10
Southern Methodist University			
Stanford University	14	31	
Stevens Institute of Technology			
Swarthmore College	2	17	
Syracuse University	7	16	7
Tennessee, University of	5	24	
Texas A. and M. College	11	48	5
Texas Technological College	10	29	1
Texas, University of	12	63	
Tufts College	5	32	
Tulane University	10	26	6
Union College	5	53	
Utah, University of	15	34	10
Vermont, University of	10	19	5
Villanova College	5	12	3
Virginia Military Institute	3	44	6
Virginia Polytechnic Institute	19	51	9
Virginia, University of			
Washington, State College of	15	52	4
Washington, University of	10	55	3
Washington University	13	26	
West Virginia University	14	36	62
Wisconsin, University of	5	60	1
Worcester Polytechnic Institute	2	50	6
Wyoming, University of	9	45	1
Yale University	7	30	1
Total	123 Branches		608
Total number of meetings			1,163
Total attendance			52,285

* Authorized by board of directors, January 30, 1941.

† Authorized by board of directors, January 30, 1941.

** Authorized by board of directors, May 24, 1940.

visors to district co-ordinators in the defense contract service.

A comprehensive summary of Section activities during the year 1939–40, based on replies to questionnaires prepared by the Sections committee, was published in the October issue of ELECTRICAL ENGINEERING, pages 425–8. This includes a table showing in detail the many types of activities in which 54 Sections participate.

Table IV. Branch Meetings Held During Last Three Fiscal Years

	Fiscal Year Ending April 30: 1939	1940	1941
Number of Branches	120	121	123
Number of meetings held	1,190	1,346	1,163
Average number of meetings	9.9	11.1	9.5
Total attendance	53,380	64,972	52,285
Average attendance per meeting	44.8	48.3	45.0
Number of student talks	725	767	608

Table V. Conferences on Student Activities

District	Location	Date
1	Rensselaer Polytechnic Institute, Troy, N. Y.	5/3–4/40
8 and 9, University of British Columbia	Los Angeles, Calif. (Pacific Coast convention)	8/27–30/40
2	Cincinnati, Ohio (Middle Eastern District meeting)	10/9–11/40
4	University of Alabama, University, Ala.	4/3–5/41
6	University of Denver, Denver, Colorado	4/18–19/41
7	University of Missouri, Columbia, Mo.	4/28–29/41
1	Rochester, N. Y. (North Eastern District meeting)	4/30–5/2/41

Table VI. Student Conventions

Sponsor (District, Section, or Branch)	Location	Date	Number of Student Papers
1	Rensselaer Polytechnic Institute, Troy, N. Y.	5/3–4/40	21
8 and 9, University of British Columbia	Los Angeles, Calif. (Pacific Coast convention)	8/27–30/40	10
4	University of Alabama, University, Ala.	4/3–5/41	6
6	University of Denver, Denver, Colo.	4/16–18/41	9
3 and New York Section	Rutgers University, New Brunswick, N. J.	4/24/41	8
7	University of Missouri, Columbia, Mo.	4/28–29/41	
2	University of Pennsylvania, Philadelphia, Pa.	4/28/41	6
1	Rochester, N. Y. (North Eastern District meeting)	4/30–5/2/41	16

In an effort to measure the value to the Sections of the surveys of Section activities made during the past few years, the committee distributed a questionnaire in April. A report based on the responses will be discussed at the conference of officers, delegates, and members at the 1941 summer convention in Toronto.

In September 1940, only 93 members of the Institute within the United States were outside of Section territories. Section membership records as of August 1, 1940, gave the total membership of the Sections in the United States as 14,338.

The Sections committee has continued its study of unassigned territory with the object of recommending further revisions when desirable. The other activities of the Sections committee have included the adoption of a trial plan for publishing information on Section meetings in ELECTRICAL ENGINEERING, plans to develop greater interest among the Sections in vocational guidance, and efforts to develop more effective distribution of the pamphlets "The Electrical Engineer" and "Engineering—A Career, a Culture".

Table I contains detailed information regarding membership and meetings of the individual Sections, table II shows a comparison over the past three years, and table VII shows the extent of student participation in Section and joint Section and Branch meetings.

STUDENT ACTIVITIES

New Student Branches were organized at the University of Connecticut, Storrs; Norwich University, Northfield, Vt.; and Manhattan College, New York, N. Y. Armour Institute of Technology and Lewis Institute, both in Chicago, were combined under the name Illinois Institute of Technology, and therefore the two Student Branches were combined into the Illinois Institute of Technology Branch. The total number of Branches at the end of the year was 123.

The students have continued their keen interest in presenting papers at the Pacific Coast convention and District meetings, presenting 11 papers in 2 sessions at the Pacific Coast convention, and 16 papers in 3 sessions at the North Eastern District meeting, in Rochester. As shown in table VII, 30 Branches co-operated with 20 Sections in holding 21 Section or joint Section and Branch meetings in which students presented 67 papers.

Only one Branch failed to report any activity during the year. Thirteen Branches held more than 15 meetings each, 27 held from 12 to 15, 30 held from 8 to 11, 36 held from 4 to 7, and 16 held from 1 to 3.

The total number of Branch meetings held during the year was 1,163, and 608 student talks were presented, both numbers being considerably lower than those for the preceding year. Although 9 Branches had 15 or more student talks, and 27 had from 5 to 14, 52 had only from 1 to 4, and 35 had none.

Of 1,641 Enrolled Students whose terms were expected to expire on April 30, 1941, 887 or about 54 per cent applied for admission as Associates. The records for the preceding year were 1,624, 911, and about 56 per cent. Tables III, IV, V, VI, and VII contain detailed information on Branch meetings, District conferences, student conventions, and student participation in Section and joint Section and Branch meetings.

Table VII. Section or Joint Section and Branch Meetings With Active Student Participation

Sections	Branches	Date	Student Talks	Attendance
Cincinnati	University of Cincinnati	5/9/40	4	195
New Orleans	Louisiana State University, Tulane University	5/13/40	2	70
Worcester	Worcester Polytechnic Institute	5/14/40	5	65
Oklahoma City	University of Oklahoma	5/15/40	1	127
St. Louis	Missouri School of Mines and Metallurgy, University of Missouri, Washington University	5/17/40	6	110
Portland	Oregon State College	5/18/40	3	99
Tulsa	University of Arkansas, Oklahoma A. and M. College	5/18/40	4	70
Utah	University of Utah	5/20/40	3	44
Florida	University of Florida	12/27/40	2	56
Pittsburgh	Carnegie Institute of Tech., Pennsylvania State College, University of Pittsburgh, West Virginia University	1/14/41	4	292
Akron	University of Akron	1/14/41	1	68
Toronto	University of Toronto	1/20/41	4	82
Vancouver	University of British Columbia	3/3/41	3	51
Los Angeles	California Institute of Tech., University of Southern Calif.	4/8/41	5	120
Houston	Texas A. and M. College, Rice Institute	4/9/41	5	68
Seattle	University of Washington	4/14/41	2	56
Cleveland	Case School of Applied Science	4/17/41	3	82
New Orleans	Tulane University	4/18/41	2	39
Minnesota	University of Minnesota	4/22/41	4	60
Louisville	University of Louisville	4/25/41	1	40
San Francisco	University of Santa Clara, Stanford University	4/25/41	3	80
Totals—20 Sections, 30 Branches, 21 Meetings			67	1,874

National • • • •

Committee Announces 1940 AIEE National Prize Awards

National prize awards for papers presented during 1940 have been announced by the AIEE committee on the award of Institute prizes. The committee had the benefit of recommendations on all except Branch papers from the chairmen of technical committees, and selection was made from all eligible papers presented in 1940. No award is being made for best paper in public relations and education as no eligible papers in this category were presented during 1940. The prizes will be awarded at the annual meeting of the Institute, June 17, 1941, during the coming summer convention at Toronto, Canada.

The announcement was made by P. L. Alger, acting chairman of the committee, for J. W. Barker, chairman. Other members of the committee are W. F. Davidson and D. M. Simmons.

Papers receiving awards in the several classifications, and their authors, are:

Best Paper in Engineering Practice: Prize awarded jointly to D. R. Shoults (A'35), M. A. Edwards (M'40), and F. E. Crever (A'37), of the General Electric Company, for their paper on "Industrial Applications of Amplidyne Generators", presented at the winter convention, January 22–26, 1940, and published in the 1940 TRANSACTIONS, pages 944–9; and to J. W. Milnor (A'13, F'30) of the Western Union Telegraph Company, for his paper on "Control of Inductive Interference Telegraph Systems", presented at the 1940 winter convention and published in the 1940 TRANSACTIONS (August section), pages 469–74. Honorable mention was made of the paper "The Development of the Civil Aeronautics Authority Instrument Landing System at Indianapolis", by W. E. Jackson, Civil Aeronautics Authority; A. Alford (A'39) and P. F. Byrne, International Telephone Development Company; and H. B. Fischer, Bell Telephone Laboratories, Inc., which was presented at the 1940 winter convention and published in the 1940 TRANSACTIONS, pages 849–58.

Best Paper in Theory and Research: Prize awarded to E. C. Starr (M'29), Oregon State College, for his two papers "High-Voltage D-C Point Discharges" and "Aircraft Precipitation-Static Radio Interference", presented at the summer convention, June 24–28, 1940, and published in the 1941 TRANSACTIONS, pages 356–62 and 363–70. Honorable mention was made of the paper "Theory of Hysteresis Motor Torque" by B. R. Teare, Jr. (A'29, M'36), Carnegie Institute of Technology, which was presented at the 1940 winter convention and published in the 1940 Transactions, pages 907–12.

Initial Paper: Prize awarded to V. E. Legg (M'37), and J. F. Given (A'28), Bell Telephone Laboratories, Inc., for their paper "Compressed Powdered Molybdenum Permalloy for High-Quality Inductance Coils", presented at the winter convention and published in the 1940 TRANSACTIONS, pages 865–72.

Branch Paper: Prize was awarded to W. H. Huggins (Enrolled Student) Oregon State College, for his paper "A Stabilized Neon-Tube Direct-Coupled Amplifier", presented at a joint meeting of the Portland Section and the Oregon State College Branch, May 18, 1940. Honorable mention was made of the paper "A New Device for Slip Determination" by W. R. Chynoweth (Enrolled Student) University of Missouri, which was presented at a joint meeting of the St. Louis Section and the Missouri School of Mines and Metallurgy, University of Missouri and Washington University Branches, May 17, 1940.

Awards being made by the various Districts for 1940 papers will be announced in future issues, as the information becomes available.

1941 Lamme Medal Nominations Due December 1

Special attention is directed to the fact that the names of Institute members who are considered eligible for the AIEE Lamme Medal, to be awarded early in 1942, may be submitted by any member in ac-

Future AIEE Meetings

Summer Convention
Toronto, Canada, June 16–20, 1941

Pacific Coast Convention
Yellowstone National Park, August 27–29, 1941

South West District Meeting
St. Louis, Mo., October 8–10, 1941

Southern District Meeting
New Orleans, La., December 3–5, 1941

Winter Convention
New York, N. Y., January 26–30, 1942

cordance with section 1 of article VI of the bylaws of the Lamme Medal committee, as quoted in the following:

The committee shall cause to be published in one or more issues of ELECTRICAL ENGINEERING, or of its successors, each year, preferably including the June issue, a statement regarding the "Lamme Medal" and an invitation for any member to present to the national secretary of the Institute by December 1, the name of a member as a nominee for the medal, accompanied by a statement of his "meritorious achievement" and the names of at least three engineers, of standing who are familiar with the achievement.

Each nomination should give concisely the specific grounds upon which the award is proposed, and also a complete detailed statement of the achievements of the nominee to enable the committee to determine its significance as compared with the achievements of other nominees. If the work of the nominee has been of a somewhat general character in co-operation with others, specific information should be given regarding his individual contributions. Names of endorsers should be given as specified in the foregoing quotation.

1941 Year Book Issued

The 1941 edition of the AIEE Year Book has been issued, in accordance with 1940–41 budget provisions. Addresses are corrected as of February 28, 1941. Copies have already been distributed to all national, District, and Section officers, Student Branch counselors, and all members of national committees. Other members desiring copies may obtain them by writing to the AIEE order department, 33 West 39th Street, New York, N. Y. The Year Book is not available to nonmembers of the Institute, nor is its use permitted for commercial, promotional, or other circularization purposes.

Section • • • •

Institute Groups Hear English Engineer

T. R. Scott, chief engineer, power cable division, Standard Telephones and Cables, Ltd., London, Eng., addressed the power group of the AIEE New York Section, New York, N. Y., April 29, 1941, the round-table group of the Michigan Section, Detroit, Mich., May 2, and a round-table conference of the Edison Electric Institute, AIEE Chicago Section, and Commonwealth Edison Company, Chicago, Ill., May 5. Mr. Scott discussed technical advances in the use of Styrene, a new insulating material being used for emergency repairs in power-cable installations damaged by air raids, which he has demonstrated before representatives of power companies in various American cities.

Mr. Scott's trip to the United States has been arranged by International Standard Electric Corporation, supply and manufacturing division of International Telephone and Telegraph Corporation, of which Standard Electric is the principal British associate, with special permission of the British Government.

Branch • • • •

Third District Students Meet at Rutgers

With a reported total of 320 persons in attendance, the 15th annual student convention of the Institute's third District was held April 24, 1941 at Rutgers University, New Brunswick, N. J. A busy full day's program provided for the presentation and discussion of 7 student technical papers during the morning session, a variety of inspection trips to near-by points of technical interest during the afternoon, and an informal banquet in the evening.

The technical program included the following papers:

"Vacuum Tube Constants by Oscillograph." Loebe Julie, College of the City of New York

"Generation and Application of Square Waves." Gabriel Blechman, New York University

"An Electronic Frequency Meter." Rudolph Dehn, Newark College of Engineering

"Electric Power Requirements for National Defense." George Gilmore, Pratt Institute

"The Barkhausen Effect in Ferromagnetism." Edward Barlow, Cooper Union

"Design and Construction of a Vacuum-Tube Voltmeter." A. J. Dolan, Brooklyn Polytechnic Institute

"Synthesis of Electric Wave Shapes by Electronic Means." Burton R. Lester, Rutgers University

A special jury consisting of Allen B. DuMont, president, DuMont Laboratories, Passaic; T. M. Hunter (A'15, M'28) president, American Transformer Company, Newark; Robert B. Litchfield, (A'17) equipment engineer at New Jersey Bell Telephone Company, Newark, awarded a first prize of $25.00 to Mr. Blechman, a second prize of $10.00 to Mr. Lester, and honorable mention jointly to Mr. Dehn and Mr. Dolan. The judges themselves contributed a purse of $10.00 to be divided between the winners of honorable mentions, because of the closeness of the competition.

R. C. Muir (A'08, F'36) vice-president in charge of engineering for the General Electric Company, revealed the depth of his interest in student engineering activities by taking time out of his busy schedule to serve as the feature speaker for the general banquet. In speaking on the topic "The Electrical Engineeer in Industry," Mr. Muir briefly reviewed the nature and significance of the more important electrical engineering developments, stressing both the technical and the human or sociological aspects. In fact, he laid special emphasis upon the latter, defining the difference between a technician and a professional engineer in terms of the balance achieved by the individual between a knowledge of purely technical matters on the one hand and an understanding of human relationships on the other hand. Mr. Muir ventured the suggestion that a fully successful career as a professional engineer and citizen might very well require a foundation comprising something like 25 per cent good technical education and as much as 75 per cent in knowledge and understanding of human relations.

Guests of Honor at the banquet in addition to Mr. Muir included Dean P. H. Daggett of the college of engineering, Rutgers; Student Branch Counselor Frederic P. Fischer of Rutgers University; President Robert C. Clothier of Rutgers University; National Secretary H. H. Henline and Editor G. Ross Henninger from AIEE headquarters, New York; and Chairman J. F. Fairman of the New York Section. Mr. Fairman gave a particularly stimulating and challenging extemporaneous message to the students at the banquet, the essential substance of which is reflected in the transcript appearing on these pages under the title "Democracy, Like Charity, Begins at Home."

Democracy, Like Charity, Begins at Home

A Challenge to Students—and Others

"IF WE believe in our Code of Professional Ethics, let's live up to it, not just talk about it. Democracy, in the Institute, or in the nation, can't be made for us; we must make it. Let's really go to work for Democracy—which, like charity, begins at home; we can't afford to continue to 'let George do it', as the classic phrase goes." So challenged Chairman J. F. Fairman of the New York Section in speaking before a group of some 300-odd Enrolled Students at the recent AIEE District 3 student convention at Rutgers University. The essential substance of his thought-provoking extemporaneous comments is reflected in the following approximate transcript.

INSTITUTE LOOKS TO YOUTH

It has been my good fortune to have attended a number of these student conventions in recent years, and I always come away wondering why the members of the Institute, as they grow older, can't retain some of the spontaneity and enthusiasm which characterizes these Student Branch activities.

Heretofore, my presence has not been sufficiently official to afford me an opportu-

nity to speak to the gathering. Hence, I can't forego this long awaited chance to relieve my mind of the burden of some thoughts that I have been storing. Perhaps something of what I say will stick with some of you and lead you to carry over more of your present enthusiasm and high ideals into your future work in the Institute and in your profession.

You will understand better what is behind my wishful thinking for the future of the Institute in your hands when I tell you that, although the New York Section has nearly 3,500 members, your meeting with something over 300 in attendance is larger by far than three out of the four general Section meetings held this year. The bright spots in New York Section activities are the meetings sponsored by the five technical groups and I ascribe this to the fact that these groups were organized by, for, and of the younger element. They were designed to give the young engineers a forum for the exchange of ideas and experiences in the fields of their special interests and they are doing so good a job and are having such interesting meetings that the older men are attending them in preference to the general Section affairs. In my opinion, this is all to the good and I believe the time is not far distant when the youth movement will take over the Section itself and show the elder statesmen how to run it as it should be run.

Some of the other large Sections throughout the country have similar divisions of their work, adapted to the interests of their members. Wherever you may be located when you leave school and get a job, go to the local Section meetings, find out how the work is organized, and volunteer for service in whatever activity interests you, or whatever activity seems to need your help. Don't wait to be asked. You probably won't be. Volunteer.

WHAT IS DEMOCRACY?

This brings me to the next thought. Most of you are shortly going to be handed a tin hat and a gun and taught how to do squads right, or whatever its modern equivalent is, in order to prepare you, if need be, to help defend Democracy. Maybe you know what Democracy is. I hope you do, and that you think it is worth defending. Perhaps some of you have been wondering a bit, as many of us who went through the same motions some 20-odd years ago have been wondering, just what it's all about. Just what is this Democracy we talk about so glibly? How do you get it and, more important, how do you *keep* it?

Make no mistake about this—I shall not presume to tell you, because I am not sure that I know. Nevertheless, I am quite sure that some of the things done in its name are not democratic, and indeed definitely bear the earmarks of a type of political philosophy we are supposed to be "neutral against". I shall give you just one concept that I keep coming back to in my own thinking. If it appeals to you as a foundation stone, you might build on it.

To me, Democracy implies that each of us to the full extent of his time and ability and taking into account his special talents, does his share in promoting the common welfare of every group of which he is a part or with which he is connected directly or indirectly. To me, Democracy, like charity, literally begins at home. It begins in the family group, the school, the college, the Student Branch and the Section of the Institute, the fraternal organization, the club, the various civic and charitable organizations, the church, and in all the other organized activities of a community. If, working together, we can make a success of such activities, it should be easy to make Democracy work in the broader fields of state and national affairs; yes, even in the very broad field of international affairs. If we can't or won't, then in my opinion we shall lose this thing called Democracy and we shall deserve to lose it.

WHY "LET GEORGE DO IT"?

If I am anywhere near right in this, my understanding of Democracy and the democratic process, I believe we have not far to go to find the reason for our present fears that our democratic system is in danger. We and many other people have not been working at it. We have largely "left it to George," and George has been a very busy man. Being busy, he had to take some shortcuts. Also, since nobody stopped him, he has been trying out some ideas of his own and naturally enough, they were principally directed to the greater glory of George. We can't blame George. He probably did the best he could. Unfortunately, we don't like the results and certainly we don't like George as well as we did.

I think we have been lazy in passing the buck to George on important matters of public interest. I think we should actively carry our own individual and definite responsibilities of citizenship.

Are you fellows going to play golf on Election Day, all day, as so many of your elders have done, in the mistaken and lazy belief that "one vote more or less won't make any difference to anybody?" Are you going to crab about how the Institute is run, and do nothing about it but crab. Are you going to stay away from church, asserting that it is full of hyprocrites who would taint your pure souls? Are you—but why go on? You have to make your own answers, and you will have to live with the consequences of your action or inaction.

Just one more thought before I conclude these rambling remarks. It seems that one school of thought assigns to technology (and that means engineers) the blame for the dislocation of our economic system. Before I got to thinking about George and his place in the scheme of things, that allegation used to annoy me very much. I was sure somebody else was to blame. Now I'm not so sure. Perhaps we have been leaving part of our job to George, and hence are partly responsible for the results.

Within the last few days, our AIEE editor asked me to review two papers, each presented by a distinguished member of the Institute before his Section. The two Sections are well separated geographically, but the authors are poles apart in thought and philosophy. Both papers were well written. I hope both will be published. But the thing that startled me wide awake was the radically different conclusions reached by these two distinguished gentlemen, starting with substantially the same facts.

What is wrong with our engineering processes when that can happen? I was brought up to believe, as an engineer—and I suppose your professors still so teach you—that if all the facts are in our possession, we should be able to reason to a sound and logical conclusion, and that generally only one real answer is possible. Of course, sometimes in mathematical processes the answers can be negative or imaginary, and in such instances you know how to interpret them or what to do with them. Apparently, in the case of these authors, the imaginary answers had too strong an appeal entirely to be resisted. Consequently, their conclusions were colored accordingly and very beautifully colored, too. But that's not the engineering process, that's the kind of special pleading that all too frequently characterizes political and other aspects of human affairs. Gentlemen, as engineers, let's leave such specious special pleading to others. Let's content ourselves with being honest.

After reading those papers, I looked up our Code of Principles of Professional Conduct. Like these authors, I hadn't read it recently either. I want to read you a few selected paragraphs from that code:

"In all of his relations the engineer should be guided by the highest principles of honor.

"The engineer should endeavor to assist the public to a fair and correct general understanding of engineering matters, to extend the general knowledge of engineering, and to discourage the appearance of untrue, unfair, or exaggerated statements on engineering subjects in the press or elsewhere, especially if these statements may lead to, or are made for the purpose of, inducing the public to participate in unworthy enterprises.

"It is unprofessional to give an opinion on a subject without being fully informed as to all the facts relating thereto and as to the purposes for which the information is asked. The opinion should contain a full statement of the conditions under which it applies.

"An engineer in responsible charge of work should not permit nontechnical persons to overrule his engineering judgments on purely engineering grounds."

I submit that such a code has something vital to do with Democracy. If we believe in it, if we have any pride in and respect for our profession and ourselves, let's not just talk about these principles, let's have the courage to live up to them.

Conference on Student Activities Held by District 6 at Denver

The 14th annual conference on student activities of AIEE District 6 was held at the University of Denver, Denver, Colo., April 18–19, 1941. Nine colleges and universities were represented at the conference, which had a total registration of 124 students and faculty members. The program included a dinner meeting with the AIEE Denver Section at which President R. W. Sorensen, District Vice-President A. L. Turner, and Doctor J. M. Gage, University of Colorado, were speakers; two technical sessions; business meetings of Branch counselors and Branch chairmen; and a final session at which President Sorensen was speaker and District prizes for papers were announced.

The business meeting of counselors voted to hold the 1942 conference at Colorado State College, Fort Collins, on April 24 and 25. The conference was previously scheduled to be held at South Dakota State School of Mines, Rapid City, but a change was requested by Professor J. O. Kammerman, counselor of that Branch, who is

absent because of military service. Professor F. B. Beatty, Colorado State College, was elected chairman of the District committee on student activities and counselor delegate to the 1941 summer convention. Professor H. S. Rush, North Dakota State College, was selected as alternate counselor delegate.

At the technical sessions, the following student papers were presented:

A Method of Magnetizing Small Permanent Magnets, **J. D. Smith and Art Siegal,** University of Denver.

Audio Control of Color, **F. A. Olson and H. B. Hansen,** University of North Dakota (presented by Robert Smith)

Frequency Response and Efficiency Measurements of a Loudspeaker, **F. H. Slaymaker,** University of Nebraska

Airways Radio Ranges, **Sam Phillips,** University of Wyoming

Amateur Television, **Robert Barthlo and Vincent Winters,** South Dakota State College

Application of the Amplidyne as a Voltage Regulator, **W. C. Brown and R. H. West,** University of Colorado

Giorgi MKS System of Units, **Dean Hendrix,** Colorado State College

An Investigation of Grid and Plate Currents in the FG-67 Thyratron, **Richard Nelson,** South Dakota School of Mines

Effects of Electricity on the Human Body, **Gus Stroebel and Allen Barstad,** North Dakota Agricultural College.

District prize for Branch paper was awarded to F. H. Slaymaker. W. C. Brown and R. H. West received first honorable mention, and J. D. Smith and Art Siegal second honorable mention.

Abstracts • • •

TECHNICAL PAPERS are previewed in this section as they become available in advance pamphlet form. Copies may be obtained by mail by remitting price indicated to the AIEE order department, 33 West 39th Street, New York, N. Y., or at five cents less per copy if purchased at AIEE headquarters or at AIEE convention or District-meeting registration desks.

The papers previewed in this issue will be presented at the AIEE summer convention, Toronto, Canada, June 16-20, 1941.

Basic Sciences

41-107—Analytical Methods of Solving Discrete Nonlinear Problems in Electrical Engineering; *E. G. Keller* (*M'40*). *20 cents by mail.* More often than not, the nonlinear problems of electrical engineering arise from discrete physical systems and are usually reducible mathematically to the solution of systems of nonlinear total differential equations or to systems of nonlinear integral equations. Six independent methods of solving discrete nonlinear problems are given in this paper. Each is illustrated by means of an electrical-engineering problem. The illustrative examples employed pertain to a-c and d-c nonlinear circuits, reluctance-induction motors, hunting of and dynamic braking of synchronous machines. References to additional methods are given in the bibliography. The 100 references listed represent approximately ten per cent of the field, but many of the entries contain bibliographies on their respective fields.

41-105—Diode Rectifying Circuits With Capacitance Filters; *D. L. Waidelich* (*A'39*). *25 cents by mail.* This paper presents the results of an investigation of the half-wave and full-wave rectifier circuits with a simple capacitance filter and using either high-vacuum or mercury-vapor tubes. An equivalent circuit is set up, such that when the tube is conducting, a mercury-vapor tube is represented by a constant voltage drop or a high-vacuum tube by a constant resistance. A detailed analysis of this circuit is carried through in the appendix, and it is found that the output characteristics depend upon three parameters. The results of this analysis are presented in the form of curves giving the angles at which the tubes begin conducting and cease conducting and also the d-c output voltage. For the more special case of no tube drop, curves of ripple voltage, maximum tube current, and tube inverse peak voltage are presented. The comparisons made between the calculated results and test results show very satisfactory agreements. It is shown that the curves given in the paper may be used in the design of rectifier circuits with capacitance filters.

Communication

41-130—ACO—Sound Recording for the Amateur; *A. L. Williams. 20 cents by mail.* Many fields of technical development have appealed to the amateur, with the result that their amateur activities therein have contributed materially both to the progress of the art and to their own personal pleasure. Amateur radio and photography are notable examples, and the recent increase in interest in home recording gives promise that this field is now ripe for amateur exploitation. Both magnetic and disk recording are particularly well adapted to amateur interest, but due to the present-time difficulty of obtaining component parts for magnetic-recording systems, the amateur is advised to concern himself first with disk recording, where all of the component parts necessary for constructing a high-quality machine are already available These component parts are discussed briefly. Disk material is considered, and some attention is given to recording characteristics suitable for amateur purposes.

41-129—The Measurement of Body Currents; *Robert S. Schwab. 15 cents by mail.* All living tissue has d-c potential differences between parts of different energy values. They are related to growth, metabolism, and the absorption of energy. Plants and all organs in animals show it. A-c potentials coming in distinct waves are found in tissues related to active motion. Muscle and nerves are electrically inactive except when stimulated. Heart is rhythmically electrically active in a special synchronous form. Brain and ganglion cells are continuously electrically active in an asynchronous way when healthy and awake; during sleep and in pathological states continuous synchrony develops. Death in all tissues is shown by total loss of both d-c and a-c potentials.

41-113—Radio Broadcasting in Canada; *A. Frigon* (*A'20*). *15 cents by mail.* The development of radio broadcasting in Canada has been very rapid. There are now 85 broadcast transmitters in daily operation. All broadcasting is under the control of the Canadian Broadcasting Corporation, an independent government corporation, which in addition to its regulatory functions operates a coast-to-coast network connecting for a nation-wide service its own 10 modern stations with almost half of the privately owned transmitters. It cannot therefore be said that radio in Canada is owned and operated by the Government, as the CBC is independent and free to apply its revenues derived from licenses and commercial operation in the best interests of its radio audience. The Canadian system is one of co-operation between a semipublic service and private ownership. Parliamentary inquiries have always found it the best suited to Canada's needs considering its vast area and relatively sparse population.

41-111—ACO—Phonograph Record Recording and Reproducing; *A. D. Burt. 20 cents by mail.* For the second time during the history of the phonograph, public interest has reached such proportions that the resultant business has become of great commercial importance. Mechanical reproducing means were concerned with the first period and electrical reproducing means with the second period. Laterally cut disks have provided the principal form used for the phonograph record. Only such historical information is included as relates specifically to the laterally cut record and the reproducing means employed. Improvement in phonograph reproduction can be obtained by designing to minimize the more obvious defects such as "wow," flutter, rumble, surface noise, and "needle chatter". The wider the reproduced frequency range becomes, the more important it is to minimize these defects. The paper illustrates how the use of the analogy between mechanical and electrical circuits facilitates the solution of the complicated mechanical and acoustical problems in this field.

Electrical Machinery

41-126—Transient Torques in Squirrel-Cage Induction Motors, With Special Reference to Plugging; *E. S. Gilfilan, Jr. and Edward Kaplan. 30 cents by mail.* When a squirrel-cage motor is switched in any way, whether while running or at rest, transient torques, which are usually several times the steady-state torque, occur and must be considered in design. It was desired to obtain a general semiquantitative view of these torques by considering a limiting case which is accessible analytically, with the expectation that a simple rule would be apparent for estimating the magnitude of these torques from design data. No such rule was found, and we must be content to exhibit limiting transient torque curves for certain types of motors in the commercial range and to provide accurate formulas for calculating such limiting torques for types not considered here.

41-127—Excitation Circuits for Ignitron Rectifiers; *H. C. Myers and J. H. Cox* (*A'26*). *20 cents by mail.* The excitation of ignitron rectifiers can be accomplished by a

considerable variety of circuits. After some experience the types used commercially have narrowed down to a few. The anode-firing method, though simplest, does not provide sufficiently positive excitation to produce a desirable degree of balance in the larger installations. Separate excitation systems have been developed which use capacitor impulses controlled with thyratron, rotating-impulse generators, and capacitor impulses controlled with saturating reactors. The capacitor-thyratron system has most flexibility of control but makes use of thyratrons which are a renewable item. The rotating-impulse generator is attractive only on large installations and here there is danger of system hunting. The saturating-reactor system constitutes a positive system which has no renewable parts. Means have been developed for either manual or automatic control.

41-124—A New Transformer for Base Load Stations; *Philip Sporn (F'30) and H. V. Putman (M'32). 15 cents by mail.* This paper describes the application of "Hipersil" to three 40,000 kva units for the Philo generating station of The Ohio Power Company. Because of "Hipersil's" ability to carry one-third more magnetic flux, appreciable savings in weight and dimensions are possible—in fact, the transformers will be shipped in oil completely assembled with bushings in place, ready to operate. Forced-oil and forced-air-cooling is provided, with proper relays for protection in the event of excessive copper temperature or failure of auxiliaries. Reliability, economy, ease of installation, and low maintenance have been the objectives sought in the design.

41-118—The Basis for the Nondestructive Testing of Insulation; *R. F. Field (M'40). 20 cents by mail.* The success of the nondestructive testing of insulation depends on the existence of a satisfactory correlation between any decrease in dielectric strength caused by deterioration of any insulation and changes in the electrical characteristics of the insulation. Such correlation does exist because of the mutual dependence of dielectric strength and low-frequency interfacial polarization on the abundance and disposition of free electrons and ions throughout the material. This polarization is defined by four parameters whose values can be determined only from current-time curves because the relaxation frequency of the polarization is below the range of bridge measurements. The method of graphical analysis of these curves suggested by K. S. and R. H. Cole in a paper presented at a recent meeting of the American Physical Society, can be used for the calculation of these parameters.

41-110—Damping and Synchronizing Torque of the Double-Fed Asynchronous Machine; *M. M. Liwschitz (M'39). 15 cents by mail.* It has required more than 20 years (L. Dreyfus—1911, R. H. Park—1933) to solve the damping problem of the d-c-excited synchronous machine. In recent times the a-c-excited synchronous machine, that is, the double-fed asynchronous machine, has become important as drive with wide speed range. For speed control at least four more main machines are necessary, two synchronous machines and two d-c machines. The total system consists of mechanical springs, electrical springs (synchronizing torques), mechanical dampings, electrical dampings, and masses. The dynamic stability of the system depends on the springs, dampings, and masses of all parts of the system. At present no work has been published about the damping and synchronizing torques of the a-c-excited synchronous machine. The object of this paper is to derive formulas for these torques. As in the case of the synchronous machine, complicated results cannot be avoided. Approximate shorter formulas are given at the end of the paper.

Electronics

41-117—Current Rating and Life of Cold-Cathode Tubes; *G. H. Rockwood (M'34). 15 cents by mail.* The life of low-voltage cold-cathode tubes is found to be determined solely by the current drawn. Tube life is terminated by the removal of the active material from the cathode surface by sputtering. The relationship between life and current drain is established on theoretical grounds and this relation checked experimentally. The application of the law relating current and life to tube ratings is discussed.

Industrial Power Applications

41-98—A New Mercury Rheostatic Element for Regulation and Control; *K. A. Oplinger (M'39). 15 cents by mail.* See May issue, page 230, for abstract incorrectly numbered there as 41-99.

41-136—A Distribution System for War-Time Plant Expansion; *J. L. McKeever (A'32). 15 cents by mail.* This paper describes the industrial distribution system recently installed in an extension to the Peterborough, Ont., plant of the Canadian General Electric Company. Use is made of the network principle but the system is thought to be unique in that it is a development of the primary network propounded by various members of the General Electric Company some ten years ago, rather than of the metropolitan type of network. Use is made of unit substations of simplified design with Pyranol-filled transformers. The 6,600-volt primaries are connected into a loop or ring main, while the 575-volt secondaries are interconnected to form a network. The network protection is extremely simple and consists merely of the inverse-time and instantaneous trips on the 575-volt network air circuit breakers at either end of the 6,600-volt loop. Advantages obtained by the use of the network system are given and a comparison is made between it and the conventional radial system as regards both function and cost.

Instruments and Measurements

41-132—The A-C Dielectric-Loss and Power-Factor Method for Field Investigation of Electrical Insulation; *Frank C. Doble (A'12). 20 cents by mail.* This paper explains in detail the shielding principles which made field testing possible, traces the history of its development, and summarizes its application as already recorded in the literature.

41-125—Relative Accuracy of Three-Phase Metering Combinations; *C. T. Weller (M'21). 15 cents by mail.* This paper grades in terms of relative accuracy several three-phase combinations of instrument transformers and watt-hour meters under various conditions. The grades range from *A* to *E*, *A* being assigned to cases where the metering combination and the conditions of application represent the best standard practice, which ordinarily approximates the ideal. In a metering combination, this means resolvability into two or more component single-phase sections. The combinations are considered principally from the instrument-transformer standpoint. Sources of uncertainty or of error are discussed, emphasizing especially difficulties sometimes encountered with wye-connected potential transformers and the effects of various secondary interconnections on the metering accuracy. The paper is summarized in one tabulation, which conveys a general idea of the performance to be expected from the metering combinations under different conditions from the accuracy standpoint. Four figures show the schematic connections of complete metering applications and of the component parts.

41-112—The Shielding of Permanent Magnets From Transient Magnetic Fields; *George J. Wey (A'38). 15 cents by mail.* Operating experience with watt-hour meters has shown that the damping magnets on a few meters each year are weakened by the magnetic fields of lightning-surge currents which may flow in the service wiring. The paper shows how ordinary forged steel magnets may be protected from such fields by shielding with a thick copper coating applied by a new high-speed copper plating process. Curves are shown comparing the shielding effect of ordinary copper plating, Schoop sprayed copper, copper-clad magnet steel, and the new high-speed copper plating. Desirable features of this method of protection are complete interchangeability between shielded and unshielded magnets and the use of conventional materials which are easy to obtain.

41-108—An Improved Frequency Meter for Commercial Power Frequencies; *K. J. Knudsen (M'38). 15 cents by mail.* This paper describes a frequency meter in which the external reactor has been eliminated by using an iron core cross-coil dynamometer. Detailed description is given of a precision calibration method, accomplished by means of a multivibrator, an oscillograph, and a variable speed generator in conjunction with an auxiliary frequency meter, having a range of two-tenths cycle. The accuracy of the 55–65-cycles instrument is within two-tenths cycle, allowing for a voltage variation of 90 to 140 volts, a ten per cent third harmonic distortion, and ambient temperatures from minus 20 to plus 45 degrees centigrade. The dynamometer can be housed in a three-and-a-half-inch case and is well adapted for use as a six-inch instrument. It is felt that this frequency meter is of particular value where space is limited, due to its compactness and the absence of auxiliary equipment.

41-106—Effect of Sapphire Crystal Orientation on the Wear of Watt-Hour Meter Bearings; *J. H. Goss (A'35). 15 cents by mail.* This paper describes the most recent of a series of studies on the life of watt-hour-meter bearing materials. It covers an investigation of the effect of jewel crystalline axis orientation upon jewel wear. Lifetime stability of meter calibration is a function of bearing wear. A study of the wear (after several years' service) of the sapphire jewel cups of meters in relation to crystalline orientation confirms predictions of another investigator; and a corroborative theory, based upon the physics of crystals, is presented.

41-119—Power Circuit Instruments for the Higher Range of Audio-Frequencies; *L. J. Lunas (M'36) and Paul MacGahan (M'15). 15 cents by mail.* The extending use being made of frequencies from 900 to 12,000 for special purposes such as induction furnaces, introduces new problems in instrument design and calibration. Previous practical a-c instruments were either of the electrodynamic or moving-iron types designed for low power frequencies or thermal and rectifier types for audio- and radio-frequencies, these latter usually being confined to measurements of only current and voltage. The ordinary low-frequency electromagnetic instruments have such high coil reactance and losses that they are unsuitable for the higher power frequencies in question without special arrangements, which are described in the paper. Furthermore, the usual calibration methods and standards as previously used for low frequencies are not adequate, and therefore new methods of calibration were introduced.

41-120—Bushing Tests; *A. L. Brownlee (A'25) and W. H. Wickham (A'41). 15 cents by mail.* This paper gives the results of power-factor tests on high-voltage bushings at test voltages up to or above the operating voltage. The results show the desirability of testing at these higher voltages. The paper also describes the findings of laboratory examinations of deteriorated bushings from which considerable information has been obtained concerning bushing deterioration.

Land Transportation

41-104—Modern Motors Serve City Transit Systems; *W. J. Clardy (M'39) and C. A. Atwell (A'41). 15 cents by mail.* City transit motors operated today include many new mechanical and electrical features. Modern vehicles differ greatly from those of a decade ago and propulsion motors contributed substantially to the advances achieved. Meeting present-day needs has required designs for 300 and 600 volts involving extensive use of new materials, application to new types of drive, and suitability for dynamic braking. Mechanical design includes unusual developments in frame construction, method of mounting, lead arrangement, ventilation, housings, and bearings. Compactness has led to ingenuity in brushholder arrangement to secure accessibility. Armatures require judicious selection of materials for shafts, cores, and commutators, as well as special seasoning and balancing procedure. Electrical design betterments have been introduced in armature slots, armature coils, field coils, and insulation. Provision for quietness and good commutation are also salient points. The new designs have resulted in high electrical and weight efficiency for series motors used on Diesel-electric buses, trolley coaches, and street cars, in comparison with old type machines. Excellent commutation has produced outstanding stability at rapid accelerating and dynamic braking rates. Vehicle performance is exceptional with respect to safety, operating efficiency, available selection of accelerating and braking rates, and the broad speed-range of the dynamic brake.

Power Transmission and Distribution

41-131—Impulse Strength as a Measure of Cable Quality; *L. I. Komives (A'41). 20 cents by mail.* The results of impulse tests on impregnated-paper insulated cables seem to indicate that, in a cable having the best obtainable insulation, breakdown occurs at a voltage for which the maximum stress is around 3,300 volts per mil. If the quality of the insulation is inferior, owing either to nonuniformity of taping or incomplete impregnation, the maximum stress value becomes less than 3,300 volts per mil and, therefore, the maximum stress obtained from impulse tests is a good measure of the uniformity of taping and the degree of impregnation. Solid, oil-filled, oilostatic, and compression cables, when new, all should have the same maximum stress at breakdown. For a given insulation thickness, the oil-filled cable, having the largest conductor diameter, will withstand the highest voltage even after aging. Oilostatic and compression cables also are expected to retain their original breakdown values after aging. Because of the decrease of the degree of impregnation in service, aged solid cables have a lower impulse strength than new ones and therefore, taping, being independent of age, is more important than the degree of impregnation. Low gas pressure cables, although originally lower than solid-type cables, in regard to impulse strength, are expected to retain this value after aging.

Production and Application of Light

41-123—The Incandescent Lamp Situation From the Engineering Point of View; *Preston S. Millar (M'13). 25 cents by mail.* At the height of its career, the incandescent electric lamp occupies a place of large importance in which its numerous good qualities contribute to its usefulness. Lamp engineering seeks high efficiency and low cost of light production with consistency of lamp performance and simplicity of application. It grapples with numerous problems and makes selection between possible alternative procedures. Its criterion is satisfaction of the public in lighting matters. Data are presented to show qualities of lamps and aspects of performance with which lamp engineering procedure has to do. Attainments of the lamp industry are reviewed. Benefits of large-scale industry leadership are asserted. Achievements and the relative standing of the American lamp industry are discussed.

Protective Devices

41-137—Field Investigations of Lightning; *C. F. Wagner (F'40), G. D. McCann (A'38), and Edward Beck (M'35). 25 cents by mail.* See May issue, page 231, for abstract incorrectly numbered there as 41-100.

41-133—The Protection of Solid Insulation by Lightning Arresters; *D. D. MacCarthy (A'28) and T. J. Carpenter (A'38). 15 cents by mail.* An investigation has been made to determine the impulse failure voltage of oil-immersed paper insulation samples made from materials used in distribution transformers. Previous investigations had largely dealt with high-voltage insulation and 1.5×40 microsecond full waves or chopped waves, rather than with the wave shapes resulting from the operation of lightning protective devices. In the present investigation volt-time puncture curves were obtained from tests on the wave front that show the puncture voltage as a function of time for different thicknesses of insulation. These curves were found to be relatively flat. In part of these tests, the magnitude and wave shape of the voltage applied to the insulation was controlled by lightning arresters or protective gaps in parallel with the insulation. The effect of repeated shots was also investigated. Voltages in excess of approximately 70 per cent of the single shot failure voltage damaged the insulation.

41-134—Dielectric Strength of Oil for High-Potential Testing of Oil Circuit Breakers; *H. J. Lingal (A'33), W. F. Skeats (M'36), and H. D. Braley (A'18). 15 cents by mail.* This paper reports the results of work done by an AIEE working group assigned to determine the minimum dielectric strength of oil for high potential testing of oil circuit breakers. Data from many tests, both 60-cycle and impulse, are collected, tabulated, and analyzed. The data cover tests on both new oil and used oils and the results are used in drawing the conclusions and recommendations offered by the authors. The paper shows that the dielectric strength of oil circuit breakers does not vary in direct proportion to the strength of oil as measured in a test cup. Recommendations are made as to the dielectric strength of oil to be used for circuit breaker testing.

41-135—New Current Transformer for Bus Differential Protection; *L. F. Kennedy (M'39) and A. T. Sinks (A'36). 30 cents by mail.* During the past five years many studies have been made of means for providing reliable bus differential protection. Practically all of these studies have resulted in proposed methods of bus protection capable of overcoming current transformer errors. This paper describes a new current transformer developed particularly for application where high speed differential protection is required. Current transformers designed with an air gap in the core are shown to be capable of maintaining an essentially constant ratio even with the high primary currents flowing into near-by external faults. With the possible error current due to current transformer differences reduced to a small percentage of the total current a reliable simple relay system is capable of distinguishing easily between internal and external faults. These air-gap

core transformers are shown to be much smaller than conventional designs for the same performance.

41-128—Protection of Low-Voltage Circuits by Air Circuit Breakers in Cascade Arrangement; *A. E. Anderson (F'40) and C. H. Black. 25 cents by mail.* This paper outlines a new solution to the problem of providing adequate short-circuit protection for low-voltage circuits operating at 600 volts or less. There are many instances where a relatively large number of main feeder circuits supply an even larger number of branch feeders. The selection of branch feeder breakers, or possibly even main feeder breakers, with interrupting ratings high enough to match the obtainable short-circuit currents may prove completely impractical when viewed with any reasonable regard for space requirements or cost. The paper describes a practical and economical solution to this problem. Air circuit breakers of varying interrupting ratings but properly coordinated designs are used in a "cascade" or series connection in such manner that in event of a severe fault, the main breakers "back up" the smaller main feeder breakers, and these in turn "back up" the branch feeder breakers.

41-115—Lightning to the Empire State Building—II; *K. B. McEachron (F'37). 20 cents by mail.* Since 1935 the author has been trying to secure oscillographic records of the wave shapes of natural lightning to the Empire State Building. The first low-speed oscillogram showing changes in current during one second was obtained in 1937. Four usable high-speed oscillograms of current peaks were obtained in 1938, including 12 oscillograms showing 12 peaks occurring in 0.28 second. During the summer of 1940, 17 strokes were recorded on the low-speed oscillograph and correlating data were obtained for most strokes on the high-speed oscillograph. Forty-one current peaks so recorded make possible the determination of the frequency of occurrence of various rates of rise, crest currents, duration, and charge. One stroke having a positive crest current of 58,000 amperes was recorded. The application of these data to transmission lines is briefly discussed.

41-116—Power Circuit Breaker Ratings; *R. C. Van Sickle (M'37). 15 cents by mail.* Circuit-breaker application is being simplified. An important step in this movement is the establishment of the various elements of a breaker rating in such relation to one another that the choosing of a breaker of adequate interrupting capacity automatically selects a breaker capable of meeting the other related requirements. A new proposal for the calculation of the interrupting current eliminates the variable of the tripping time of the circuit breaker. This paper shows that with the standardizing of the tripping time, the rated making current, rated momentary current, rated five-second current and rated interrupting capacity can be related to simplify further the breaker application.

41-114—Mechanical Simplicity of Air-Blast Circuit Breakers; *H. W. Haberl (A'28) and Otto Jensen. 15 cents by mail.* This paper deals with the mechanism of air-blast breakers. Included is a general description of breakers with voltage ranges from 4 to 230 kv followed by a detailed description of some of the mechanism common to all types. Three distinct types of breakers are followed through a sequence operation and schematic diagrams are included to clarify the mechanical details. Included in the diagrams are photographs of the actual breaker being described, also a sequence oscillogram and a staged interruption test. A fourth type of breaker is described, but schematic diagrams of this type are not included as they are similar to one of the previous types.

41-122—D-C Machine Flashover and Bus Short Circuit Protection; *T. B. Montgomery (M'41) and J. F. Sellers (A'34). 25 cents by mail.* In protecting d-c bus systems recognized tripping methods which have been generally accepted are reviewed. Two methods of bus construction for large d-c steel-mill applications having large concentration of power, and reasons for their justification are presented. Bus construction of two typical large hot-strip mill applications are described. Test oscillograms and characteristic test curves for both heavy and nominal short-circuit interruptions are given for air circuit breakers protecting these systems in the conventional manner. D-c machine characteristics are developed under short-circuit conditions and formulas and short-circuit current curves are presented. A novel protective relay system which has proved successful in practice is described, and the improved protection indicated by tripping current and time values are shown in curve form.

41-121—System Short-Circuit Currents—Proposed New Calculating Procedure for Application of Interrupting Devices and Relays; *W. M. Hanna (A'26), H. A. Travers (A'41), C. F. Wagner (F'40); C. A. Woodrow (M'41) and W. F. Skeats (M'36). 20 cents by mail.* This paper is the report of a group assigned to investigate the problem under the auspices of the subcommittee on circuit breakers, switches, and fuses of the AIEE protective devices committee. The method proposed consists of the determination of the highest value of symmetrical short-circuit current for any type of fault as obtained by dividing voltage by subtransient reactance. Multiplying factors are then assigned according to the basis of rating of the equipment concerned and the speed of its operation. This procedure is more realistic in its appraisal of the contribution of the d-c component than the present decrement curves and with the increase in complexity of systems over recent years and the present wide and increasing use of high-speed relaying offers other advantages, both in simplicity of application and accuracy.

Personal • • •

A. J. Duncan (A'09) formerly president of the Texas Electric Service Company, Fort Worth, has been made chairman of the board of directors. **J. B. Thomas** (M'28) formerly vice-president and general manager of the company, has been appointed president and general manager. Mr. Duncan was born in 1877 at Pittsburgh, Pa. After having been employed for several years by the Cleveland Electric Illuminating Company, the Brush Electric Company, and the General Electric Company, he became lighting engineer for the Interborough Rapid Transit Company, New York. He was with that company for five years and about 1906 was made secretary and general manager of the Citizens' Railway and Lighting Company of Fort Worth. About 1915 he became president of the Fort Worth Power and Light Company, and in 1932 was made president of the Texas Electric Service Company. Mr. Thomas was born July 19, 1891, in San Marcos, Texas, and received the degree of bachelor of science in mechanical engineering from Texas Agricultural and Mechanical College in 1911. In 1912 he became a draftsman and engineer for the Texas Power and Light Company, and in 1916 was made resident engineer in charge of construction. From 1916 to 1917 he was office engineer for that company. From 1917 to 1919 he served in the United States Army Coast Artillery Corps, and returned to the Texas Power and Light Company as resident engineer and later as assistant to the chief engineer. From 1921 to 1929 he was chief engineer for the company and in 1930 became vice-president in charge of operations for the Texas Electric Service Company, later occupying the positions of executive vice-president and general manager. He has been active on several Institute committees, and is also a member of The American Society of Mechanical Engineers.

A. P. M. Fleming (M'14, F'34) director of research and education, Metropolitan-Vickers Electrical Company, Ltd., Manchester, England, and local honorary secretary of the Institute for Great Britain, has been awarded the Faraday Medal for 1940 by the Council of the Institution of Electrical Engineers (Great Britain). Doctor Fleming was born January 16th, 1881, at Newport, Isle-of-Wight, and received the degree of master of science from Finsbury Technical College, London, in 1898. In 1898 he became assistant engineer of the London Electric Supply Corporation, and later carried on experimental testing for Elliott Brothers, electrical instrument makers. From 1900 to 1902 he was with the Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., and from 1902 to 1905 was insulation specialist for the British Westinghouse Electric and Manufacturing Company, Ltd., Manchester, England, which subsequently became Metropolitan-Vickers Electrical Company, Ltd. In 1905 he became transformer designer for the company, and in 1908 assistant superintendent in charge of manufacture and design of transformers. He was made superintendent of the transformer, winding and insulating department in 1911 and became director of research and education in 1914. In 1915 he was sent to the United States by the British government to make an investigation of American institutions organized to conduct industrial research. Doctor Fleming is the author of several books and of many technical articles, and holds the honorary degrees of master of science, Manchester, and doctor

of engineering, Liverpool. He is a past president of the Institution of Electrical Engineers, and is a fellow of the Institute of Patentees and a member of the Institution of Mechanical Engineers.

F. D. Knight (M'25) formerly superintendent of production for the Boston Edison Company, Boston, Mass., has become assistant to the operating vice-president of the Hartford (Conn.) Electric Light Company. **H. W. H. Wellington** (A'38) formerly assistant superintendent of production, will succeed Mr. Knight as superintendent of production for the Boston company. Mr. Knight was born in Limerick, Maine, October 27, 1883, and received the degree of bachelor of science in electrical engineering from the University of Maine in 1909. From 1909 to 1925 he was superintendent in charge of construction for projects undertaken by the Stone and Webster Company of Boston, Mass., in Fort Worth, Tex., Baton Rouge, La., Boston, Mass., Springfield, Mass., and Hartford, Conn. In 1925 he became superintendent of the generating department, Edison Electric Illuminating Company of Boston (now Boston Edison). He is also a member of The American Society of Mechanical Engineers. Mr. Wellington was born June 23, 1890 in Boston, Mass. In 1911 he became associated with the General Electric Company, at Lynn, Mass., and worked in several departments before joining the Stone and Webster Company, Boston, Mass., as a construction wireman. He later worked as a draftsman for the Boston Elevated Company and was also with the Edison Electric Illuminating Company of Boston in the technical division for a short time. After working with the American Car Works of St. Louis, Mo., and the Union Electric Light and Power Company of St. Louis he joined the Edison Electric Illuminating Company of Boston in 1921 as electrical technical engineer. In 1924 he became assistant to the superintendent of the production department, and in 1937 was made assistant superintendent of production.

Wilfred Sykes (A'09, F'14) formerly assistant to the president of the Inland Steel Company, Chicago, Ill., has been elected president of the company. Mr. Sykes was born in Palmerston, North New Zealand, December 8, 1879, and attended the University of Melbourne. From 1900 to 1905 he was employed by D. Durcks and Company (afterwards Knox-Schlapp and Company), Australian agents for Allegemeine Elektricitats Gesellschaft of Berlin, Germany. He was assistant to the chief engineer, manager of the Sidney branch, and later chief electrical engineer for the concern in Melbourne. When the Allegemeine Elektricitats Gesellschaft agency was transferred to Staerker and Fischer he took charge of electrical work in Victoria, Tasmania, and South Australia, and in 1906 went to Berlin as engineer in the foreign department of the Berlin company. In 1909 he came to the United States and was employed as engineer by the Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa. In 1921 he became affiliated with the Steel and Tube Company of America, Chicago, Ill., and in 1923 joined the staff of the Inland Steel Company. He was a manager of the Institute from 1917 to 1921, and has been active on several Institute committees. He is also a member of The American Society of Mechanical Engineers and the American Institute of Mining and Metallurgical Engineers, and is the author of several technical papers.

W. F. Grimes (A'19, M'27) radio material officer of the 11th Naval District, San Diego, Calif., has been promoted to the rank of lieutenant-commander in the United States Naval Reserve. Mr. Grimes was born in Pasadena, Calif., February 21, 1895, and studied electrical engineering at the University of Southern California. From 1917 to 1918 he was with the staff commander-in-chief of the United States fleet, working on maintenance of communication equipment. In 1918 he became assistant in the Naval Radio Research Laboratory at the Bureau of Standards, Washington, D. C. From 1919 to 1924 he was expert on radio for the bureau of engineering, Navy Department, Washington, D. C. In 1925 he joined the Westinghouse Electric and Manufacturing Company, and did sales and engineering work for the Los Angeles, Calif., office. From 1931 to about 1936 he was engaged as radio interference engineer for various Los Angeles trade associations, and in 1936 became chief engineer (later manager) of the Radio Interference Engineering Bureau of Los Angeles. During 1941 he has been serving as radio material officer in the United States Naval Reserve. He is the author of numerous technical publications.

C. E. Brown, Jr. (A'40) formerly assistant to the president of the Okonite Company and the Okonite-Callender Cable Company, Washington, D. C., has been elected vice-president of the companies. He will also remain in charge of the Washington, D. C., office. Mr. Brown was born August 2, 1894 in Buffalo, N. Y., and received the degree of bachelor of arts from Princeton University in 1917. From 1919 to 1925 he was with the Central Electric Company, Chicago, Ill., and during 1925 was country sales manager in charge of sales in about 19 states outside Illinois. In 1925 he became affiliated with the Okonite Company, as manager of the power and light department in the Chicago area. In 1930 he was transferred to the executive offices of the company in New York, and became executive assistant to the president. Since 1934, in addition to retaining the latter position he has been sales executive for the company in Washington, D. C. He is also a member of the American Society of Naval Engineers.

W. H. Pratt (A'02, F'13) retired consulting engineer of the meter division of the General Electric Company, Lynn, Mass., has been chosen as the first recipient of the New England Award newly established by the Engineering Societies of New England, Inc. Mr. Pratt was born December 29, 1872, at Waltham, Mass. He received the degree of bachelor of science in electrical engineering from the Massachusetts Institute of Technology in 1894, and shortly afterward was employed by the Judson L. Thompson Manufacturing Company of Waltham, Mass., as a draftsman. In June 1895 he entered the testing department of the General Electric Company, at Lynn, Mass., and in November of the same year was appointed foreman in charge of the standardizing laboratory. In 1897 he became assistant in meter and instrument design in the engineering department of the company, and later was made designing engineer in charge of meter and instrument design. He is the owner of several patents.

F. B. Jewett (A'03, F'12) president of the National Academy of Sciences is a member of the board of the newly created National Science Fund of the National Academy of Sciences (see page 308). Doctor Jewett who is a vice-president of the American Telephone and Telegraph Company, New York, N. Y. and chairman of the board of directors of the Bell Telephone Laboratories, is serving as a member of the National Defense Research Committee. Other Institute members who will serve on the board of the National Science Fund are **K. T. Compton** (F'31) president of the Massachusetts Institute of Technology, Cambridge; **Gano Dunn** (A'91, F'12) president of the J. G. White Engineering Corporation, New York, N. Y., and chairman of the advisory power committee organized by the National Defense Advisory Commission; and **R. A. Millikan** (M'22) director of the Norman Bridge Laboratory of Physics and chairman of the executive council of California Institute of Technology, Pasadena.

J. B. Noe (A'03, F'30) assistant to the planning engineer of the Consolidated Edison Company of New York, Inc., New York, N. Y., retired recently after 43 years with the company. He was born in Elizabeth, N. J., March 27, 1876, and received the degree of bachelor of science from Rutgers University in 1897. From 1897 to 1901 he was employed as a meter tester by the Edison Electric Illuminating Company (now the Consolidated Edison Company of New York, Inc.), and for a year was also electrical engineer of the Consolidated Telegraph and Electrical Subway Company. In 1902 he became assistant to the superintendent of transmission and distribution of the Consolidated Edison Company, and in 1910 was made assistant to the chief electrical engineer. He became assistant engineer of the electrical engineering department in 1925. He is also a member of the American Standards Association.

H. L. Hazeltine (A'20, F'40) engineer of insulation for the Sterling Varnish Company, Haysville, Pa., has been elected vice-president of the company. Mr. Hazeltine was born May 26, 1891, at Miller Place, N. Y. He received the degree of bachelor of philosophy from Yale University in 1913, and from 1913 to 1915 was assistant instructor in physics in the Sheffield Scientific School of Yale University. After a year as foreman for the White Adding Machine Company, New Haven, Conn., he became instructor in physics at the Georgia School

of Technology, Atlanta, in 1916. In 1917 he became head of the department of electricity of the School of Industrial Arts, Trenton, N. J., and in 1920 became affiliated with the Sterling Varnish Company, as eastern manager. From 1923 to the present he has been engineer of insulation for that company. He is also a member of the American Society for Testing Materials.

F. S. Bacon, Jr. (A'37) formerly sales engineer for the central station division of the Westinghouse Electric and Manufacturing Company at Boston, Mass., has been appointed assistant central station manager, New England district. **F. R. Benedict** (A'40) has been made engineering manager for the New England district, and **L. O. Dorfman** (A'19, M'28) formerly engineering manager for the New England district has been appointed assistant to the district engineering manager at East Pittsburgh, Pa. **C. F. Herbold** (A'33) formerly engineer of the small motors division, is now manager of industrial relations for the small motors division. **S. C. Leyland** (A'40), who was relay application engineer for the company, has been made relay section engineer for the meter division, and **R. M. Smith** (A'35) formerly section engineer, is now manager of the engineering department of the wiring device division.

C. J. Grece (A'22) assistant general foreman in the underground division of the Consolidated Edison Company of New York, Inc., New York, N. Y., has retired, having been with the company for 40 years. Mr. Grece was born in Jersey City, N. J., September 5, 1884. He joined the Consolidated Edison Company in 1900, and has served since as underground helper, tester, foreman, and assistant general foreman.

C. I. MacGuffie (A'27) has been appointed manager of sales, electric welding section, industrial department, General Electric Company, Schenectady, N. Y. He was formerly assistant manager.

R. C. Glancy (A'18, M'26) formerly operating results engineer, has been appointed general staff engineer, Bell Telephone Company of Pennsylvania, Philadelphia, Pa.

Obituary • • •

Morton Githens Lloyd (A'08, M'10, F'12) chief of the safety codes section at the National Bureau of Standards, Washington, D. C., died April 26, 1941. He was born September 10, 1874, in Beverley, N. J. He received the degrees of bachelor of science, 1896, doctor of philosophy, 1900, and electrical engineer, 1908, from the University of Pennsylvania. He also studied at Harvard University and the Friedrich Wilhelms Universitat, Berlin. From 1899 to 1902 he was an instructor in physics at the University of Pennsylvania, and in 1902 became associated with the Bureau of Standards, where he served first as laboratory assistant and later as assistant physicist and associate physicist. He was technical editor of the *Electrical Review and Western Electrician*, Chicago, Ill. from 1910 to 1916. In 1917 he returned to the Bureau of Standards as associate electrical engineer. He was the author of several technical articles and of many of the technical publications of the Bureau of Standards. In 1910 he received the Edward Longstreth Medal of the Franklin Institute. He was president of the International Association of Electrical Inspectors, past president of the American Society of Safety Engineers, and was also a member of the United States National Committee of the International Commission on Illumination, the National Fire Protection Association, the National Safety Council, and the American Standards Association. He served on the Institute committee on safety and was a past chairman of the Washington Section.

William Shirley Richhart (A'08, M'13) superintendent of power production at the Spy Run generating plant of the Indiana Service Corporation, Fort Wayne, Ind., died April 9, 1941. He was born September 26, 1881, in Noblesville, Ind. and received the degree of bachelor of science in electrical engineering from Purdue University in 1905. After having been employed by the Allis-Chalmers Manufacturing Company, Cincinnati, Ohio, for a short time, he did research work at Purdue University, Lafayette, Ind., and in 1906 became an instructor in electrical engineering at the University of Pennsylvania, Philadelphia. From 1911 to 1916 he was with the Westinghouse Electric and Manufacturing Company as an engineer in the service department, and in 1916 became affiliated with the Public Service Commission of Indiana, Indianapolis. In 1917 he joined the Indiana Service Corporation as an electrical engineer in the light and power department. He subsequently served as assistant operating engineer, power operating engineer, electrical distribution engineer and power production engineer. From 1935 to 1938 he was sent on leave of absence to do special engineering work in Indianapolis and New York. He was also a member of The American Society of Mechanical Engineers.

Roscoe Schaeffer (A'32, M'36) superintendent of engineering for the Oklahoma Gas and Electric Company, Oklahoma City, Okla., died April 18, 1941. He was born April 10, 1892, at Ludlow, Illinois, and received the degree of bachelor of science in electrical engineering from Iowa State College in 1915. From 1915 to 1916 he was assistant superintendent of a municipal steam-electric power plant at Buffalo Center, Iowa, after which he became associated with the General Electric Company, Schenectady, N. Y., doing work in the testing department, and in 1919 was made assistant to the general foreman of the General Electric testing department. From 1919 to 1923 he did electrical engineering work with the Remy Electric Company, Anderson, Ind., and with the William A. Baehr organization, Chicago, Ill. In 1923 he joined the Oklahoma Gas and Electric Company, Oklahoma City, as assistant to the construction superintendent and later became assistant to the general superintendent of operation. In 1926 he was employed by the Byllesby Engineering and Management Corporation of Chicago, Ill., continuing as resident electrical engineer on property of the Oklahoma Gas and Electric Company at Oklahoma City. In 1936 he was re-employed by the latter company as superintendent of engineering. He was vice-chairman of the AIEE Oklahoma City Section.

Reuben E. Nyswander (M'22) dean, school of science and engineering, University of Denver, Denver, Colo., died April 8, 1941. He was born January 4, 1878, in Antwerp, Ohio, and received the degrees of bachelor of arts, 1901, and master of arts, 1904, from Indiana University, and the degree of doctor of philosophy from Cornell University in 1908. From 1898 to 1903 he was an assistant in physics at Indiana University, Bloomington, and 1903–06 magnetic observer for the United States Coast and Geodetic Survey. He became an instructor in physics at Indiana University in 1908. After a year there he accepted a position as professor of physics at the University of Denver. In 1919 he was made director of the school of electrical engineering, and when it was reorganized into a combined school of science and engineering he became associate dean of the department. He was made dean of the school in 1937. Dean Nyswander was the author of several technical articles, and had invented a polarization photometer. He was chairman of the AIEE Denver Section, 1931–32.

Andrew Patterson (A'08, M'38) chief engineer of the Southwestern Gas and Electric Company, Shreveport, La., died April 4, 1941. He was born June 6, 1881, in Baltimore, Md., and was educated at Baltimore Polytechnic Institute. From 1903 to 1905 he was engaged in plant and distribution system redesign and reconstruction for H. M. Byllesby and Company, Chicago, Ill., and for the Oklahoma Gas and Electric Company, Oklahoma City. In 1905 he was electrical engineer in plant layout for the Muskogee Gas and Electric Company, and electric superintendent of layout construction sponsored by H. M. Byllesby and Company at Fort Smith, Ark. In 1914 he became engineer on electric plant construction for the Dawes Electric Company, later the Southwestern Gas and Electric Company, and was also electric superintendent, a position which he held until he was appointed chief engineer for the company in 1926.

Frederick John Cunningham (A'19) superintendent of communications, Consumers Power Company of Michigan, Battle Creek, died in April 1941. He was born February 28, 1886, in Saginaw, Mich. In 1911 he was employed by the Au Sable Electric Company, in constructing and operating a 140,000-volt line between Five Channels Dam and Flint, Mich. From 1912 to 1915 he was load dispatcher for the Au Sable Company at Saginaw, Mich., and in 1915 took charge of the eastern division of Consumers Power Company, which was formerly the Au Sable Company. After a year as division superintendent there, he was transferred to division superintendent of the southern division of the Consumers Power Company, at Battle Creek, a position which he held until his death.

Membership • •

Recommended for Transfer

The board of examiners, at its meeting on May 22, 1941, recommended the following members for transfer to the grade of membership indicated. Any objection to these transfers should be filed at once with the national secretary.

To Grade of Member

Adams, L. J., electrical engineer, Warner Brothers Pictures, Inc., Burbank, Calif.

Baker, B. P., development engineer, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.

Bohn, D. I., electrical engineer, Aluminum Company of America, Pittsburgh, Pa.

Drake, D. K., assistant Montana transmission and protection engineer, Helena, Mont.

de la Serna, R. T., chief engineer, Cia de Electricidad del Sud Argentino, S. A., Buenos Aires, Argentina.

Deming, P. S., engineer, Oklahoma Gas and Electric Company, Enid.

Dickinson, R. C., section engineer, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.

Diehl, R. P., electrical engineer, Park City Consolidated Mines Company, Park City, Utah.

Duff, C. H., meter engineer, Hydroelectric Power Commission, Toronto, Ont., Can.

Fleming, H. C., member of laboratory staff, Bell Telephone Laboratories Inc., New York.

Hagee, A. C., engineer, Rural Electrification Administration, Washington, D. C.

Hellwarth, A. R., electric system, Detroit Edison Company, Detroit, Mich.

Hill, L. A. W., design engineer, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.

Horelick, S., president, Pennsylvania Transformer Company, Pittsburgh, Pa.

Hough, W. R., engineer in charge of a-c motor design, Reliance Electric and Engineering Company, Cleveland, Ohio.

Hummel, R. C., technical adviser, West Coast Telephone Company, Everett, Wash.

Jochem, T. B., experimental engineer, Cutler-Hammer, Inc., Milwaukee, Wis.

John, K. W., electrical engineer, United States Rubber Company, Detroit, Mich.

Lallier, W. C., transmission engineer, Wisconsin Telephone Company, Milwaukee, Wis.

Lockwood, L. E., assistant to division operating superintendent, Public Service Company, Evanston, Ill.

Marsh, H. H., assistant general superintendent Duquesne Light Company, Pittsburgh, Pa.

McClure, E. L., assistant system engineer, Wisconsin Electric Power Company, Milwaukee, Wis.

Miner, E. E., construction electrical engineer, The Glenn L. Martin Company, Baltimore, Md.

Parker, C. N., engineer, The Nevada–California Electric Corporation, Riverside, Calif.

Pell, Eric, electrical engineer, Cutler-Hammer, Inc., Milwaukee, Wis.

Rawlins, H. L., section engineer, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.

Robinson, T. A., electrical engineer, United States Smelting Refining and Mining Co., Salt Lake City, Utah.

Roby, F. H., welding engineer, Square D Company, Milwaukee, Wis.

Roush, C. G., manager, Westinghouse Electric and Manufacturing Company, Kansas City, Mo.

Salton, H. D., development engineer, Pennsylvania Transformer Company, Pittsburgh, Pa.

Saxe, John, manager, electric utility companies in Costa Rica, Costa Rica.

Sessions, R. C., partner, Sessions and Sessions, Cleveland, Ohio.

Stetler, F. E., district foreign wire relations supervisor, Wisconsin Telephone Company, Milwaukee, Wis.

Sullivan, R. J., electrical engineer, Commonwealth and Southern Corporation, Jackson, Mich.

Witzel, E. R., electrical engineer, Kohler Company, Kohler, Wis.

35 to grade of Member

Applications for Election

Applications have been received at headquarters from the following candidates for election to membership in the Institute. Names of applicants in the United States and Canada are arranged by geographical Districts. If the applicant has applied for direct admission to a grade higher than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the national secretary before June 30, 1941, or August 31, 1941 if the applicant resides outside of the United States or Canada.

United States and Canada

1. North Eastern

Blomstedt, H. D., Narragansett Electric Company, Providence, R. I.

Campbell, H. E., General Electric Company, Schenectady, N. Y.

Fjeld, J. M., New York Power and Light Corporation, Albany, New York.

Franklin, I. L., General Electric Company, Schenectady, N. Y.

Gronbeck, J. W., Narragansett Electric Company, Providence, R. I.

Haner, L. P., E. I. du Pont de Nemours and Company, Incorporated, Station B, Buffalo, N. Y.

Hogg, J. E., General Electric Company, Schenectady, N. Y.

Hoyt, G. A., General Electric Company, Schenectady, New York.

Kidder, J. W. (Member re-election), New England Telephone and Telegraph Company, Boston, Mass.

Merkling, W. G., Central New York Power Corporation, Oswego, N. Y.

Schaefer, F. J., Wm. H. J. Hooper, Boston, Mass.

Shappee, F. C., Central New York Power Corporation, Minetto, N. Y.

Smith, W. M., F. W. Sickles Company, Chicopee, Massachusetts.

2. Middle Eastern

Ali, N. J., 125 Hough Street, Morgantown, W. Va.

Berezher, J., Cleveland Electric Illuminating Company, Cleveland, Ohio.

Boisseau, A. C., General Electric Company, Philadelphia, Pa.

Byrne, J. W., Bell Telephone Company of Pennsylvania, Pittsburgh, Pa.

Chase, M., Rural Electrification Administration, Washington, D. C.

Delahooke, H. J., North Electric Manufacturing Company, Galion, Ohio.

Finn, E. B., Insulation Manufacturers Corporation, Cleveland, Ohio.

Gieser, A. B., Potomac Electric Power Company, Washington, D. C.

Gillenwater, G. A., Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.

Green, C. R., Austin Company, Cleveland, Ohio.

Hamilton, H. L., I-T-E Circuit Breaker Company, Philadelphia, Pa.

Havercamp, W. B., WGAL, Incorporated, Lancaster, Pa.

Heiges, G. E. (Member), Heiges McCullough Company, Incorporated, Sharon, Pa.

Hufford, D. W. (Member), War Department, Corps of Engineers, U. S. Engineer Office, Huntington, W. Va.

Jensen, O., I-T-E Circuit Breaker Company, Philadelphia, Pa.

Kerr, M. P. (Member), Wheeling Electric Company, Wheeling, West Va.

Kuhn, H. R., Trumbull Electric Manufacturing Company, Norwood, Ohio.

Link, L. C., North Electric Manufacturing Company, Galion, Ohio.

Ludwig, C. H., Potomac Electric Power Company, Washington, D. C.

Mack, R., Cleveland Electric Illuminating Company, Cleveland, Ohio.

Marsh, C. O., Jr., National Bureau of Standards, Washington, D. C.

McLain, H. C. (Member), Rural Electrification Administration, Washington, D. C.

Mikina, S. J. (Member), Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.

Moldenhauer, E. W., Rural Electrification Administration, Washington, D. C.

Oeltjen, W. O., Rural Electrification Administration, Washington, D. C.

Polson, J. T., Cleveland Electric Illuminating Company, Cleveland, Ohio.

Prasek, C. J., Cleveland Electric Illuminating Company, Ashtabula, Ohio.

Shanzraw, R. L. (Member), Rural Electrification Administration, Washington, D. C.

Simpson, W. E., Potomac Electric Power Company, Washington, D. C.

Sparing, W. H., Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.

Talley, D. (Member), c/o Chief Signal Officer, Munitions Bldg., Washington, D. C.

Vergilio, J. L., 504 Erie Building, Cleveland, Ohio.

Vlach, C. J., Cleveland Electric Illuminating Company, Cleveland, Ohio.

Whalin, C. V., Jr., Potomac Electric Power Company, Washington, D. C.

Wildman, J. R., Hickok Electrical Instrument Company, Cleveland, Ohio.

Wilent, G. W., Atlantic Refining Company, Philadelphia, Pa.

Woods, T. B., Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.

3. New York City

Ellis, W. F., Gibbs and Cox, Incorporated, New York, N. Y.

Engel, G. C., General Time Instruments Corporation, New York, N. Y.

Francis, W. R., Western Union Telegraph Company, New York, New York.

Knapp, M. H., Simplex Wire and Cable Company, New York, N. Y.

Lake, F. J., Consolidated Edison Company of New York Incorporated, New York, N. Y.

Lawrence, J. G. (Member), Caribbean Architect-Engineer, New York, N. Y.

O'Meara, T. J., Manhattan College, New York, N. Y.

Seely, T., Public Service Electric and Gas Company, Newark, N. J.

Tyrner, J. M., Wilson Welder and Metals Company, Incorporated, New York, N. Y.

Zinn, M. K. (Member), Bell Telephone Laboratories, Incorporated, New York, N. Y.

4. Southern

Amerine, H. G., Jr., Tennessee Valley Authority, Knoxville, Tennessee.

Boysworth, J. T., Carolina Aluminum Company, Badin, N. C.

Cecil, H. G. (Member), 505 Cumberland Street, Bristol, Va.

Cooper, W. R., Tennessee Valley Authority, Chattanooga, Tenn.

Fort, W. G. S., United States Army, 62nd Signal Battalion, Fort McPherson, Ga.

Johnson, W. M., Florida Power and Light Company, Miami, Florida.

Owens, J. R., Memphis Light, Gas and Water Division, Memphis, Tenn.

Sigmon, R. M., Jr., Southern Bell Telephone and Telegraph Company, Columbia, S. C.

Smith, C. D. (Member), South Carolina Power Company, Charleston, S. C.

Watkins, W. W. (Member), United States Rubber Company, Hogansville, Ga.

5. Great Lakes

Anger, E. G., Square D Company, Milwaukee, Wisconsin.

Baring, J. W. (Member), Commonwealth Edison Company, Chicago, Ill.

Barnum, W. L., Watervliet Paper Company, Watervliet, Michigan.

Callstrom, B. M., Jr., Southwestern Illinois Coal Corporation, Steelville, Illinois.

Carlson, A. E., Dumore Manufacturing Company Racine, Wisconsin.

Davis, R. S., Bull Dog Electric Products Company, Detroit, Michigan.

Hornbacker, G. B., Central Illinois Light Company, Peoria, Ill.

Jensen, H. A., Nash Kelvinator Corporation, Kenosha, Wisconsin.

Knoff, H. C., Public Lighting Commission, Detroit, Michigan.

La France, P., North Plant, Michigan Alkali Company, Wyandotte, Michigan.

Lynn, R. G., American Hoist and Derrick Company, St. Paul, Minn.

Phelan, J., Indiana and Michigan Electric Company, South Bend, Indiana.

Road, R. A., Duncan Electric Manufacturing Company, Lafayette, Indiana.

Schofield, L. B., Commonwealth Edison Company, Chicago, Ill.

Sherman, V. W. (Member), Chrysler Corporation, Highland Park, Michigan.

6. North Central

Forsman, E. H., Continental Air Lines, Incorporated, Denver, Colorado.

Shaffer, R. S., Montgomery Ward Company, Denver, Colorado.

7. South West

Crail, R., Wichita High School East, Wichita, Kansas.

Lichtenfels, I. W., General Electric Company, St. Louis, Mo.

8. Pacific

Bridgwater, M. M., Arizona Power Corporation, Prescott, Arizona.

Curry, N., 1615 E. First Street, Long Beach, California.

Williams, M. D., General Electric Company, Oakland, California.

9. North West

Corfield, R. J. (Member re-election), Utah Copper Company, Garfield, Utah.

Hoffman, W. L. (Member re-election), Puget Sound Power and Light Company, Seattle, Washington.

Guirkin, L. C., Bonneville Power Administration, Portland, Oregon.

Schulz, G. R., 1233 N. W. 12th Avenue, Portland, Oregon.

Searles, P. D., Oregon Institute of Technology, Portland, Oregon.

Trippett, B. H., Big Lakes Box Company, Klamath Falls, Oregon.

10. Canada

Jones, A. R. (Member), Canadian General Electric Company, Peterborough, Ont., Canada.

McKie, W. M., Canadian General Electric Company, Limited, Peterborough, Ont., Canada.

Rogers, C. L., Hydro Electric Power Commission, Toronto, Ont., Canada.

Total, United States and Canada, 101

Elsewhere

Dessart, J. E., Tongshan Mine, c/o The Kailan Mining Administration, Tongshan, North China.

Gerstmann, B., Bayley and Grimster, Carlton, Melbourne N3, Australia.

Pfeifer, H. P. (Member), Nottebohm Trading Company, Apartado 193, San Salvador, El Salvador, C. A.

Stokvis, L. G. (Member), Compagnie generale d'Electricite, 54 Rue de la Boetie, Paris, France.

Woodward, A. G. V., New Zealand Military Forces, Trentham, New Zealand.

Total, elsewhere, 5.

Recent Section Meetings

Section	Date	Speaker	Topic and Activity	Attendance
Akron	4/ 8/41	W. E. Haskell, N. Y. Herald Tribune	War News and Censorship; motion pictures	103
Central Indiana	4/25/41	N. C. Pearcy, Pub. Utilities Engg. & Serv, Co.	Electricity in the Steel Industry; motion pictures	75
Chicago	2/ 6/41	D. C. Prince, G.E. Co.	Trends in Engineering	150
		R. W. Sorensen, pres., AIEE	Talk	
		H. H. Henline, nat. sec., AIEE	Talk	
	2/13/41	H. M. Richardson, G.E. Co.	Plastics, Particularly for Insulating; power group meeting	103
	2/27/41	T. O. Millard, G.E. Co.; E. J. Novak, cons. engr.; J. F. Calvert, Northwestern Tech. Inst.	Low Voltage Network Distribution Systems for Industrial Plants and Buildings; industrial group meeting	116
	3/13/41	L. R. Potadle, A.T.&T. Co.	Stevens Point-Minneapolis Cable; joint with Western Soc. of Engrs.	217
	4/ 3/41	I. T. Faucett, General Cable Corp.	Wire and Cable Developments; election of officers; joint with WSE	113
	4/10/41	Major C. W. Leihy	Aspects of the National Power Pool, Defensively and Afterwards; luncheon meeting	130
	4/24/41	R. M. Schaffer, F. E. Andrews, Hatch, A. F. Hibbeler, and Mr. Sagendorf	Round table discussion of distribution problems	90
Cleveland	4/17/41	F. R. Mautz, Western Reserve Univ.	Applications of Electricity to Medicine	82
		J. D. Andrew, student	The Right Angular Hyperbolic Spiral—A Criterion for Art	
		P. R. Kendall, student	Special Applications of Radio Equipment	
			Joint with Case School Branch	
Columbus	2/12/41	E. G. Romeiser, Illinois Elec. Porcelain Co.	Porcelain for Insulators; joint with Ohio State Univ. Branch	35
	2/18/41	Homer Dudley, Bell Tel. Labs.	The Vocoder, or Remaking Speech Electrically	65
	3/13/41	W. R. Giladorf, Spaulding Fibre Co.	Manufacture of Laminated Phenolic Sheets, Rods, and Tubes	17
	3/26/41	F. M. McKay, Columbus & So. Ohio Elec. Co.	Fundamentals of Rate Making; joint with Ohio Univ. Branch	46
	4/10/41	E. R. Raper, Springfield City Hospital Plant	Equipment of the Springfield Hospital	24
Connecticut	4/22/41	F. Cowan, A.T.&T. Co.	Sun Spots and Telephone Service; joint with New Haven Astron. Soc.	92
Denver	4/18/41	J. M. Cage, Univ. of Colorado	Problems in Vacuum Tube Development	130
		R. W. Sorensen, pres. AIEE	Brief talk	
		A. L. Turner, vice-pres., North Cent. Dist.	Brief talk	
East Tennessee	4/15/41	J. E. Housley, Aluminum Co. of America	Power Dispatching at the Alcoa Aluminum Reduction Works; dinner	65
Fort Wayne	2/18/41	C. M. Summers, G.E. Co.	High Potential Testing Equipment for Quantity Production	30
		F. J. Baker, Home Tel. & Tel. Co.	Trends in Communication Systems	
	3/13/41	W. L. Everitt, Ohio State Univ.	Fundamental Principles of Frequency Modulation	160
	4/21/41	R. W. Sorensen, pres., AIEE	Engineering Horizons, Limited	80
Houston	4/ 9/41	L. K. Davis and B. W. Pike, students	Localized Annealing of Rock Bit Bodies	68
		J. B. Parchman, student	A Privacy System Using Frequency Translation	
		R. S. Hoff, student	A High-Impedance Vacuum-Tube Wattmeter	
		O. M. Martin, student	Mathematical Analysis of Nonlinear Circuits	
			Joint with Rice Inst. and Texas A.&M. Branches	
Louisville	4/25/41	F. R. Ellwanger, student	Testing of transformers using the cathode-ray oscillograph; joint with Univ. of Louisville Branch	40
Lynn	10/22/40	B. Adams	A Program of Super-Magic	1,000
	11/12/40	Commander L. C. Stevens, U.S.N.	Development in Naval and Aircraft Equipment Shown by the War	900
	12/10/40	Major D. Sears, Universal newsreel cameraman	Get That Picture	900
	12/17/40	F. B. Silsbee	Electrical Work of the National Bureau of Standards	400
	1/ 7/41		The Story of the Coast Guard; motion pictures	600
	1/28/41	Ruth Bryan Owen	This Business of Diplomacy	1,000
	2/11/41		Illumination	1,000
	3/11/41		Safety Around Electrical Machinery	500
	3/25/41	Capt. J. Craig	The Philippines Today	1,000
Madison	4/17/41	H. L. Rusch, A. C. Nielsen Co.	Measuring Listening Habits of the American Radio Audience	39
Maryland	4/21/41		Prize paper contest	74
		K. J. Affansiev	Properties of Magnetic Materials (first prize)	
		H. J. Shafer	Development of Magnetic Theory (second prize)	
		J. A. Harber	A Voltage Regulator for Synchronous Machines (third prize)	
Memphis	4/15/41	Allen Pettee, General Cable Corp.	Recent Development in Wire & Cable Construction	22
Michigan	4/15/41	L. A. Hawkins, G.E. Co.	Research in World War; election of officers	175
Minnesota	4/22/41	W. Weden, student	Frequency Modulation	60
		K. Carlson and John Storm, students	Glass-Fiber Insulation	
		M. Haugen, student	Oscillations Due to Loudspeaker-Microphone Feedback	
		T. Hedman, student	Black Light	
			Joint with Univ. of Minn. Branch	
	4/28/41	J. W. Butler, G.E. Co.	Application of Series Capacitors in All Types of Circuits	44
Nebraska	12/ 4/40	E. E. Chilberg, Cent. Nebr. Pub. Power & Irrigation Dist.	Mechanical and Electrical Design of the Transmission Lines	16
N. Mex.–W. Texas	4/ 2/41	R. W. Sorensen, pres., AIEE	Engineering Horizons, Limited; election of officers	53
New Orleans	3/28/41	P. G. Whitmore, Ebasco Services, Inc.	Electric Distribution Practices	101
Niagara Frontier	4/17/41	H. M. Cushing, Buff., Niag. & East. Power Corp.	Oswego Steam Station	58
North Texas	4/21/41	Major E. W. Porter, Air Corps	The Use of Electricity in Modern Airplanes	84
Philadelphia		H. N. Ekvall, Phila. Elec. Co.	Minimum Insulation Level for Lightning Protection of Medium-Voltage Lines	72
		E. W. Boehne, G.E. Co.	Traveling Waves on Very Short Lines	
			Election of officers	
Pittsburgh	4/ 8/41	C. S. Barrett, Carnegie Inst. of Tech.	X-Rays in Industry; election of officers; joint with elec. sec. ESWP	170
	4/22/41	G. B. Dodds and W. E. Marter, Duquesne Light Co.	Protective Relays for Power Systems and Elec. Equipment; joint meeting with elec. sec. of ESWP	126
Pittsfield	11/ 5/40	Carl Robinson	Southeastern Alaska; dinner	975
	11/26/40	K. K. Palmer, G.E. Co.	Creative Imagination, How to Train and Use It; colloquium series	75
	12/ 3/41	J. T. Flynn, writer	The Influence of the Election and the War on Business; dinner	1,010
	12/10/40	M. F. Beavers	Presentation of paper, "Effect of Load Factor on Operation of Power Transformers by Temperature," by V. M. Montsinger	20
		T. E. Palmer	Presentation of paper, "Lightning Currents in Arresters at Stations," by I. W. Gross and W. A. McMorris; colloquium series	
	1/ 7/41	Richard W. Rowan	Secret Agents Against America	1,025
	1/14/41	S. M. Humphrey, Taylor-Winfield Corp.	New Developments in Resistance Welding	58
	2/ 4/41	R. D. Evans, MIT	How Atoms Affect Your Life	960
	2/11/41	P. H. Light, G.E. Co.	Dynamic Overvoltages on Power Systems	15
	3/ 4/41	Howard Higgins	Among the Spirits	1,000
	3/25/41		Four papers presented in competition with four from Schenectady Section; competition won by Pittsfield	175
	4/ 6/41	Fulton Lewis, Jr., commentator	What's Happening in Washington	1,050
Portland	12/10/40	H. P. Beckendorf, Pacific Tel. & Tel. Co.	Community Dial Telephone Exchanges	45
	1/30/41	A. Bailey, A.T.&T. Co.	Coastal Harbor Radio Stations of the Bell System; joint with IRE	95
	3/31/41	W. C. Smith, G.E. Co.	Transformer design and operation	40
	4/16/41		Annual prize papers meeting	70

Recent Section Meetings (continued)

Section	Date	Speaker	Topic and Activity	Attendance
		H. E. Bixby and G. H. Bliesener	Use of Electrical Energy to Heat Rural and Urban Dwellings	
		C. B. Carpenter and U. H. Messenger	A Rectifier With Constant Current Output	
		W. E. Enns	A-C Network Analysis Using Resistance Networks (first prize)	
		O. W. Hurd	Automatic Tie-Line Load Control	
		R. E. McCoy	Division of Load Among a Group of Generators (second prize)	
	4/22/41	R. J. Collins, Pacific Tel. & Tel. Co.	Forecasting	29
Rochester	10/10/40	F. H. Roby, Square D Co.	Precision Timing as Applied to Welding and Industrial Control	78
	10/24/40		Fall party	85
	11/ 7/40	B. O'Brian, Univ. of Rochester	Measurement of Sun's Variability by Telemetering Balloons	60
	11/26/40		Round table discussion of radio progress in 1940	35
	12/ 5/40	C. A. Clark, International Tel. Devel. Corp.	IT&T Selenium Rectifiers	55
	1/ 9/41	G. V. Kullgren, G.E. Co.	Application Engineering Problems	92
	1/16/41		Annual bowling party	45
	2/ 6/41	C. Tuttle, Eastman Kodak Co.	Applications of Photoelectric Photometry in Industry	110
	2/19/41		Round table discussion of new requirements of the Nat. Elec. Code	50
	3/ 6/41	F. S. Goucher, Bell Tel. Labs. Inc.	The Microphone and Research	276
	4/ 3/41	E. M. Bouton, Westinghouse Elec. Elevator Co.	Vertical Transportation	56
St. Louis	4/16/41	A. L. Hughes, Washington Univ.	The Cyclatron	61
San Francisco	3/28/41	H. E. Becker, W.E.&M. Co.	Design, Construction, Application, and Operation of Ignitrons	110
	4/11/41	F. S. Benson, Pacific Gas & Elec. Co.	Electrical Features of Avon Steam Plant; dinner	70
	4/25/41	J. G. Stephenson, student	Hot-Cathode Oscillograph for Recording High Impulse Voltages	80
		W. R. Morton, student	Control of a Shunt Motor by Use of Permatrons	
		J. R. Burch, student	Electric Fencing	
			Joint with Univ. of Santa Clara and Stanford Univ. Branches	
Saskatchewan	2/13/41		Election of officers	5
	3/ 7/41		Executive committee meeting	4
	4/ 7/41		Executive committee meeting	6
Seattle	3/25/41	A. D. Moir, Bunker Hill Smelter Staff	17 Years Engineering in Europe; joint of four founder societies	170
	4/14/41	D. Gjesdahl, student	Radiant Heating Application to Homes	56
		H. J. Winsor, student	Survey of Naval Marine Propulsion	
			Joint meeting with Univ. of Wash. Branch	
Sharon	4/11/41	A. L. Draper, Buhl Planetarium	The Pageant of Easter	125
South Bend	4/29/41	T. W. Dugdale, Ind. & Mich. Elec. Co.	Carrier Current Relays and High-Speed Reclosing Breakers	52
Spokane	4/11/41	A. LeRoy Taylor, vice-pres., North West Dist.	Engineering Education	27
Syracuse	4/17/41	Wm. Bailey, Cornell-Dubilier Elec. Corp.	Application of Capacitors to Industrial and Power Circuits	115
Toledo	4/22/41	R. W. Sorensen, pres., AIEE	Engineering Horizons, Limited; dinner	50
Toronto	4/ 4/41	V. G. Smith, Univ. of Toronto	The Use of Matrices in Communication; illustrated	84
	4/18/41	C. A. Powel, W.E.&M. Co.	Electricity in the National Defense	275
	4/25/41	J. Satterly, Univ. of Toronto	Liquid Air, illustrated; election of officers	199
Washington	4/ 8/41	E. D. Merrill, Capital Transit Co.	Financing Urban Transit	100
		C. A. Robinson, Chesa. & Potomac Tel. Co.	Some Problems of Management Under Present Day Conditions	
		M. L. Sperry, Washington Gas Light Co.	Washington Gas Light Company and National Defense	
		A. G. Neal, Potomac Elec. Pwr. Co.	Operation Under the Washington Sliding Scale Arrangement	
			Meeting in honor of 34 past chairmen	
	4/19/41		Inspection trip through Bethlehem Steel Co.	120
	4/22/41	H. H. Henline, nat. sec., AIEE	Is the Institute Fulfilling Its Obligations to the Engineer; junior technical session	28
	4/24/41	T. J. MacKavanagh, Catholic Univ.	Is the Institute Fulfilling Its Obligations to the Engineer; junior technical session	20
	4/29/41	F. M. Defandorf, National Bureau of Standards	Is the Institute Fulfilling Its Obligations to the Engineer; junior technical session	15
West Virginia	4/16/41	W. E. Vellines, Jr., C.&P. Tel. Co.	Improved Instrumentalities in Intercity Telephone Plant Design	32
Worcester	4/25/41	R. W. Sorensen, pres., AIEE	Engineering Horizons, Limited; dinner	35

Recent Branch Meetings

Branch	Date	Speaker	Topic and Activity	Attendance
Arizona, Univ. of	11/26/40	D. Carter, student	Differential Equations	9
	12/ 3/40	J. C. Clark, counselor	The Importance of Temperamental Characteristics	9
	12/10/40		Business meeting	8
	12/17/40		Open house	32
	1/ 7/41	J. C. Clark, counselor	Getting a Job	9
	1/14/41	J. C. Clark, counselor	Getting a Job (concluded)	7
	2/ 4/41	R. Bookman, student	A Practical Problem in Communication	6
	2/11/41	R. Bookman, student	A Practical Problem in Communication (concluded)	6
	3/ 4/41	G. Floyd, student	Mercury Arc Rectifiers	6
	3/11/41	S. Goldman, student	The Characteristics of Transformer Insulating Materials	6
	3/25/41		Business meeting	6
	4/ 1/41	G. Floyd, student	Station Circuits	5
		R. Bookman, student	Prime Movers	
Arkansas, Univ. of	4/16/41	C. Pittman, student	Mercury Arc Rectifiers	20
		W. Dortch, student	Application of Seismographs	
		L. Shackelford, student	Corona Causes and Prevention	
	4/23/41		Election of officers	15
Brooklyn Poly. Inst. (D.)	3/ 4/41	A. Anderson, Underwriters Labs.	The National Electrical Safety Code	35
	3/11/41	S. Frangoulis, student	The History of Television	35
	3/21/41		Inspection trip through Underwriters Labs.	40
	4/ 1/41	A. Dolan, student	The Design and Construction of a Vacuum-Tube Voltmeter	40
	4/ 9/41	P. Thomas, W.E.&M. Co.	Demonstration	300
	4/24/41		Annual convention at Rutgers Univ., New Brunswick, N. J.	45
Brooklyn, Poly. Inst. (B.)	3/17/41	Mr. Krowl, N.Y.C. Tunnel Authority	Design and layout of the lighting and signal equipment in the Queens-Midtown Tunnel	25
	4/21/41	Robin Beach	Experiences in connection with several court cases	16
Calif. Inst. of Tech.	3/ 7/41		Inspection trip through Paramount sound studios	42
	3/14/41		Inspection trip through Columbia recording studios	10
	4/ 2/41		Inspection trip to the Southern Calif. Edison Co. test dept.	35

Recent Branch Meetings (continued)

Branch	Date	Speaker	Topic and Activity	Attendance
	4/ 7/41	C. B. Stadum, student	The Behavior of Insulators in Hydrogen	
		R. E. Kingsmill, student	The Shielding Effects of Transmission Lines	
			Joint with Los Angeles Section, and Univ. of So. Calif. Branch	
Calif., Univ. of	4/ 4/41		Inspection trip through Alameda cross-bar exchange	10
	4/14/41		Executive committee meeting	10
	4/14/41	J. Stephenson, student	Trip through the cross-bar telephone exchange	34
		R. C. Balsley, student	Low Voltage Short-Circuits on Distribution Systems	
		J. Burch, student	Electric Fencing	
Carnegie Inst. of Tech	9/27/40	G. W. Murdock, student	Carbon	50
	10/ 4/40	J. Jenkins, student	Electronic Musical Instruments	50
	10/11/40	J. Darnall, student	Rural Electrifications	50
	10/18/40	G. Klotzbaught, student	Transient Phenomena	50
	10/25/40	G. Wheeler, student	Unit Power Plants	50
	11/ 1/40	Wm. Preece, student	Aeronautical Instruments	50
	11/ 8/40	G. B. Wilson, student	Plastics and Their Application in the Electrical Industry	50
	11/14/40	W. A. Needs, student	Electric Furnaces in Steel Production	50
	11/22/40	R. W. Gilliland, student	The Ionosphere	50
	12/ 6/40	M. L. Levy, student	Gem Cutting	50
	12/13/40	R. Herpick, student	The Story of the Akron	50
	1/10/41	A. Helfer, student	Phonograph Recording	50
	2/ 7/41	L. Drugmong and G. McElwee, students	Frequency Modulation	50
	2/14/41	H. Cooper, student	Battleship Power Plants	50
	2/21/41	C. T. Sinclair, vice-pres., Dist. 2	Advice to the Embryo Engineer	50
	2/28/41	C. A. Powel, W.E.&M. Co.	Application Engineering	50
	3/ 7/41	C. M. Martsolf, Bell Tel. Co.	System Planning Engineering	50
	3/14/41	R. L. Kirk, Duquesne Light Co.	How, Where, and What (Engineering Counsel)	50
	3/21/41	S. Balaban, student	The Incandescent Light	50
	3/28/41	T. B. Whitson, J. J. Biddle Co.	Megger Practice	50
	4/ 4/41	G. T. Fouse, student	Fourth Dimension	50
	4/18/41	F. C. Hesch, student	The Electron Microscope	50
	4/25/41	R. DeStefano, student	Fluorescent Lighting	50
Clarkson Col.	4/23/41	A. R. Powers, counselor	Advantages of the AIEE	15
Colorado State Col.	4/11/41	H. Nuce, student	Electrical Accidents	16
		D. Hendrix, student	MKS System of Units; election of officers	
Colorado, Univ. of	4/ 9/41	W. C. Brown and R. H. West, students	The Amplidyne as a Voltage Regulator; election of officers	35
Columbia University	4/ 7/41		Business meeting	15
	4/24/41		Business meeting	15
	5/ 5/41		Business meeting	15
Conn., Univ. of	2/20/41	E. S. Lee, vice-pres., North East. Dist.	The Prominence of Measurements in Industry; inaugural meeting	159
	2/28/41	H. P. Stone, student	De-Ion Circuit Breakers	22
	3/21/41	J. H. Lampe, dean of engg.	Talk on experiences with power companies; election of officers	24
Cooper Union (E.)	4/11/41	B. Shmulevitz, student	A Survey of Frequency Modulation	25
Cornell Univ.	4/16/41	E. T. B. Gross	Euclid Applied to Circle Diagrams	38
Detroit, Univ. of	1/14/41	T. S. Cawthorne, Weston Elec. Inst. Co.	Design Details of Electrical Instruments	54
	2/26/41		Social meeting	63
	3/12/41	Wm. Dean, senior	Fundamentals of Radio Broadcasting; motion pictures	58
Drexel Inst. of Tech.	4/ 9/41	T. P. Moody, N. Y. Shipbuilding Co.	Problems of Modern Transit Ship Design	55
Duke Univ.	10/ 1/40	W. J. Seeley	AIEE activities	22
	10/15/40	G. Bennett, Durham Public Service Co.	Situations met by a public service engineer	21
	11/ 5/40	C. E. Vail, Duke Univ.	Engineering Experiences at the World's Fair	19
	11/19/40	O. Meier, Jr., counselor	Demonstration of fluorescent lighting circuits	25
	12/10/40	T. S. Shinn, Carolina Power & Light Co.	Engineering Safety	21
	1/ 7/41		Talks on various subjects by faculty members	20
	1/28/41	Members of the Durham Fire Dept.	Demonstrations on safety precautions and first aid treatment	28
	2/28/41		Discussion of engineers' show	25
	3/ 4/41	H. Hart, Duke Univ.	Happiness	28
George Washington Univ.	9/25/40	F. Hermach, student	Electrical Units and Standards	26
	10/ 2/40		Semiannual engineers' mixer	155
	11/ 6/40	H. H. Rogge, W.E.&M. Co.	The Electrical Engineer as a Salesman	39
	12/ 4/40	D. C. Coyle, consulting engr.	Engineering Economics of Capitalism	73
Georgia Sch. of Tech.	4/18/41	K. Weisiger, Southern Bell Tel. & Tel. Co.	The Engineer's Place in National Defense	53
Harvard Univ.	2/20/41	J. P. Newton, student	Analysis of the Capacitor Motor	27
		F. W. White, Jr., student	Spark Discharge in Air at Atmospheric Pressure	
	3/13/41	C. L. Dawes, Harvard Univ.	Alexanderson Thyratron Motor	30
	3/27/41		Motion pictures	20
Illinois Inst. of Tech.	4/ 4/41	Robert Zane, Okonite Corp.	Discussion of wires and cables; motion picture on Okonite products	45
	4/18/41		Election of officers	40
	4/24/41		Annual smoker	85
Illinois, Univ. of	2/19/41	H. L. Oleson, Weston Electric Inst. Co.	Meet a Meter	75
	2/26/41	E. S. Lee, G.E. Co.	The Prominence of Measurements in Industry	90
Iowa State Col.	4/23/41		General discussion	29
Iowa, Univ. of	4/16/41		Motion pictures	40
	4/30/41	E. L. Goss, student	Ultrasonics	33
		F. C. Vernon, student	Construction of Commutators	
		B. Hills, student	Polyphase Currents in Squirrel Cage Motors	
Johns Hopkins Univ.	2/ 7/41	R. Weller, student	Relays and Their Operations	18
		C. Bechtel, student	Velocity Modulation of Electron Discharge	
	2/21/41	I. C. Tillman, student	Geiger Counters	16
		R. Bell, student	Expulsion Gap Protection	
	3/ 7/41	R. D. Case, student	Test Equipment for Transformers	16
		E. Melvin, student	Ultrahigh-Frequency Propagation	
	3/21/41	W. L. Wilkerson, student	Electric Locomotives	17
	4/ 3/41	E. Eager, student	Conowingo Dam	28
	4/11/41		Election of officers	32
Kansas, Univ. of	3/25/41	J. L. Hamilton, vice-pres., South West Dist.	Engineering—Past, Present, and Future	20
	4/ 3/41	R. York, student	Feedback	40
		J. Laidig, student	Commutation Currents	
Kentucky, Univ. of	4/11/41		Discussion of recent inspection trip	50
	4/25/41		Election of officers	30
Lehigh Univ.	12/19/40		Dinner	71
	3/20/41	W. H. Vogelsberg, student	The Hammond Electric Organ	42
	4/17/41	W. H. Formhals, W.E.&M.Co.	Electrical Equipment for Modern Machine Tools	45

Recent Branch Meetings (continued)

Branch	Date	Speaker	Topic and Activity	Attendance
Maine, Univ. of	4/10/41	David Byer, student	Trip to Ford River Rouge Plant and W.E.&M. Co.	8
		Mr. Brown, student	Research laboratory at M.I.T.	
		C. Preble, student	Experiences in summer employment	
	4/22/41		Election of Branch chairman	16
	4/28/41	R. W. Sorensen, pres., AIEE	Engineering Horizons, Limited	222
Mich. Col. of M.&T.	4/15/41		Social meeting	40
Michigan State Col.	4/ 9/41	Mr. Wills, U. S. Weather Bureau	The Weather	26
	4/22/41	C. E. Fishbeck, Detroit Edison Co.	System Operation	32
Michigan, Univ. of	4/22/41	O. S. Duffendak, Univ. of Mich.	The Electron Microscope	43
Minnesota, Univ. of	3/ 5/41	Ming-China Swen, student	Engineering and Living Conditions in China; motion pictures	32
Missouri Sch. of M.&M.	3/19/41	B. Sexton, student	G.E. developments of the past year	17
		M. Block, student	Nomographs for Electrical Calculations	
		L. Kucker, student	Electron Microscope	
	4/ 1/41		Motion pictures	52
Missouri, Univ. of	10/29/40	G. Green, student	Fluorescent Lighting	36
		P. Smith, student	Lighting, the Incandescent Lamp	
	2/18/41	L. A. Nickell, Columbia Ice Co.	Setting Up of Small Power Plants; Operation of an Ice Plant	23
	4/ 1/41		Discussion of future activities	25
Montana State Col.	4/ 8/41	Mr. Williams, Montana Power Co.	Watt-Hour Meters	25
Nebraska, Univ. of	4/16/41	Mr. Pappas, student	The New KFOR Transmitter	39
Nevada, Univ. of	2/25/41	L. N. Roberts, Pacific Tel. & Tel. Co.	New Requirements in Industrial Leadership	19
	3/ 4/41		Preparations for Engineers' Day	28
	4/22/41	R. L. Shipp, student	The Hysteresograph	17
	4/29/41	L. L. Stoffel, Ohio Carbon Co.	Carbon Manufacturing; election of officers	19
New Hampshire, Univ. of	4/24/41		Election of officers	19
New Mexico State Col.	4/17/41		Election of officers	11
New Mexico, Univ. of	4/17/41		Election of officers	14
New York Univ. (E.)	4/ 2/41	I. Ritter, N.Y.U.	Exterior Ballistics	23
	4/30/41		Business meeting	17
N. C. State Col.	4/ 1/41		Discussion of plans for Engineers' Fair	50
	4/15/41	W. H. Blue, student	Description of the District conf. on student activities	37
	4/22/41		Election of officers	46
N. Dak. State Col.	4/ 3/41		Discussion of future papers	15
	4/ 8/41		Discussion of papers to be presented at student convention; election of officers	16
N. Dak., Univ. of	4/ 8/41	R. E. Smith and K. Smith, students	Ultraviolet Rays	16
		P. Olson and H. Hanson, students	The Coloratron	
	4/23/41		General discussion	14
Ohio State Univ.	2/ 6/41	J. T. Newman, student	Electricity Up to the Time of Franklin	38
	2/12/41	E. G. Romeiser, Illinois Elec. Porcelain Co.	Porcelain the Paragon of Insulators	70
	2/20/41	J. Cumming, student	Duties of a Substation Crew Man	28
	3/ 3/41	F. O. Wisman, student	Synthetic Symmetry in Mutual Inductance Balance	29
	3/7–8/41		Inspection trips and technical sessions; joint with Univ. of Cincinnati and Ohio Northern Univ. Branches	39
Ohio Univ.	10/23/40	P. Ford, student	Who Are the Engineers	12
	11/20/40		Business meeting	15
	3/ 5/41		Business meeting	17
	3/26/41	F. M. McKay, Southern Ohio Elec. Co.	Fundamentals of Rate Making; joint with Columbus Section	30
	4/30/41		Election of officers	10
Oklahoma, Univ. of	4/ 3/41	J. Straiton, student	Inverse Feedback of Rectified Radio Frequency; motion pictures	25
Oregon State Col.	2/19/41	W. R. Volheye, Oregon Bureau of Labor	Obligations of employers and workmen under Oregon Safety Code	28
	3/ 6/41	C. J. Hawkes, Electric Storage Battery Co.	Storage Batteries in Industry	56
	4/ 3/41	C. C. White, L. Chaffin, and J. N. Paszkowski, students	Symposium: Desirable Training for the Engineering Profession	28
Pennsylvania State Col.	4/2–9/41		Inspection trip	57
	4/28/41	J. O. Perrine, A.T.&T. Co.	The Artificial Creation of Speech	800
Pennsylvania, Univ. of	4/28/41		Annual student branch convention	185
Pittsburgh, Univ. of	9/26/40	J. V. Heish, student	Types of oil deposits and use of instruments in development work	90
	10/ 3/40		Motion pictures	90
	10/10/40	H. H. Miller, student	The Signal Generator—Its Operation and Applications	89
		J. Dugan, student	Marine Mines in Our Coastal Defense	
	10/17/40	H. A. Brant, student	Current Diversion	89
	10/24/40	R. C. Gorham, counselor	Middle Eastern District meeting	
		W. P. Smith, student	History of Eta Kappa Nu	
	10/31/40		Motion pictures	89
	11/ 7/40	C. W. Drake, W.E.&M. Co.	Outline of various jobs	90
	11/14/40	R. A. Kirkpatrick, Union Pacific Railroad	Boulder Dam	90
	11/21/40	James Rial, student	Function of the Engg. and Mines Committee of Y.M.C.A.	88
		Dr. Farmer, university chaplain	Value of Religion	
	11/21/40	F. N. Blum, student	Pennsylvania Electric Co.	88
		C. O. Beltz, student	The Manufacture of an A-C Motor	
	12/12/40	L. A. Terven, West Penn Pwr. Co.	Growth of Power Utilities	89
	1/ 9/41	E. A. Holbrook, dean of engg.	National Defense Program	89
	1/16/41	L. Barranti, student	Fluorescent Lighting	90
		R. Parker, student	Hydrogen Cooled Generators	
	1/23/41	W. D. Brown, Duquesne Light Co.	Primary System of Duquesne Light and Its Interconnections	90
	2/13/41	J. Unitus, U. S. Secret Service	Know Your Money	89
	2/20/41	Mr. Compton, Duquesne Light Co.	Relay Protective Devices	89
	2/27/41	S. Kovacevic, student	High Speed Photography	90
		J. Quinn, student	Electrical Precipitation Applied to Cleaning Gases	
	3/ 6/41	D. I. Baun, Aluminum Co. of America	Aluminum Company of America's Power Holdings in the U. S.	90
	3/13/41		Annual presentation of Eta Kappa Nu pledges	87
	3/20/41	W. G. Crouch, Prof.	Why We Go to See a Tragedy	87
	3/27/41	J. Barclay Whitson, J. G. Biddle Co.	The Megger Instrument	89
	4/ 3/41	D. Ornitz and A. Lasday, students	The Mass Spectograph	89
	4/17/41	R. Powell, student	Concrete Research	
	4/24/41	John McWade, student	Frequency Modulation	81
Pratt Inst.	3/29/41		Inspection trip through X-Ray Division of W.E.&M. Co.	7
	4/ 3/41	W. Beagan, student	Sperry Rail Testers	35
		H. Pinkham, student	Measurement of Light	
		G. E. Gilmore, student	Electrical Power Requirements for National Defense	
	4/18/41	P. Thomas, W.E.&M. Co.	Demonstration	91
Purdue Univ.	4/16/41	H. P. St. Clair, American Gas & Elec. Corp.	The theory and characteristics of multiwinding transformers	50

Recent Branch Meetings (continued)

Branch	Date	Speaker	Topic and Activity	Attendance
Rice Inst.	3/13/41	J. L. Hamilton, vice-pres., South West Dist.	Advantages of AIEE membership; joint with Texas A.&M. Col. Branch	58
	4/ 9/41	L. K. Davis and B. W. Pike, students	Localized Annealing of Rock Bit Bodies	68
		R. S. Hoff, student	A High Impedance Vacuum Tube Wattmeter	
		J. Parchman, student	A Privacy System Using Frequency Translation	
		O. M. Martin, student	Mathematical Analysis of Nonlinear Circuits	
			Joint with Texas A.&M. Branch and Houston Section	
Rutgers Univ.	1/15/41	R. Kennedy, student	The Future of Engineering at Rutgers	30
		S. Mason, student	The Mechanical Integraph and Planimeter	
		M. Scherb, student	Frequency Modulation	
	2/27/41	H. Johnson, Rutgers Univ.	Illustrated talk on trip to Greenland	31
Santa Clara, Univ. of	1/14/41	W. Morton, student	Processes involved in reducing timber to lumber	14
	1/28/41	J. Ganahl, student	Construction of the Prado Dam	15
	2/26/41	Mr. Ryan, student	Safety in the Electrical Testing Laboratory	21
	3/11/41	J. Susoeff, student	Electricity in Medicine	11
		F. M. Howe, student	Functions of the Line Crew of the P.G.&E. Co.	
	3/28/41	J. Dorn, student	Applications in Lighting	10
	4/23/41	W. Morton, student	Speed Control of Shunt Motors; election of officers	13
S. Dak. State Col.	10/ 2/40		Motion pictures	22
	10/16/40		Demonstration on fluorescent lighting	25
	11/20/40		Discussion on frequency modulation	23
	12/ 4/40		Discussion on frequency modulation	15
	1/ 8/41		Motion pictures	25
	2/ 5/41		Demonstration of electrical method of transposing international code signals into a typewritten message	25
	2/19/41		Discussion on nomography	15
	3/ 5/41		Election of officers	25
	3/18/41		Business meeting	7
	4/ 2/41		Explanation of television methods	27
	4/16/41	H. Johnson and K. Hammer, students	Papers	12
	4/18–19/41	R. Barthle and V. Winters, students	Amateur Television	8
	4/30/41		Discussion	12
S. Dak. State Sch. of Mines	4/ 3/41		Discussion of future plans; election of Branch chairman	12
So. Calif., Univ. of	3/27/41		Inspection trip through RCA recording studios	20
	4/ 8/41	Mr. Kingsmill, student	The Shielding Effect of Towers on Transmission Line Conductors	120
		Messrs. Dawson and Stadum, students	The Behavior of Insulators in Hydrogen	
		L. Wilson, student	Power Factor Measurements by Vacuum Tube Voltmeter	
		Mr. Romero, student	New Frontiers in Southern Calif.	
		R. Hedges, student	An Electrical Method for Automatic Musical Transposition	
			Joint with Los Angeles Section and Calif. Inst. of Tech. Branch	
	4/15/41	W. Cline, Don Lee Television Sta. WeXAO	Problems met with in building and operating a television station	25
Stanford Univ.	4/16/41	R. V. Howard, Radio Station KSFO	Theoretical and Practical Aspects of Wave Propagation as Applied to Radio Broadcasting; election of officers	65
	4/26/41		Inspection trip through the P.G.&E. Co.	8
Swarthmore Col.	3/13/41		Election of officers	7
	4/15/41	M. I. Allen, Philadelphia Elec. Co.	Some Aspects of Utility Power Service	26
Tennessee, Univ. of	1/22/41		Motion pictures	16
	2/13/41		Motion pictures	50
Texas A.&M. Col.	3/13/41		Discussion	21
	3/27/41		Motion pictures	43
	4/17/41		Election of chairman	23
Texas Tech. Col.	4/21/41	W. D. Price, Texas-New Mexico Utilities Co.	Automatic Control; election of officers	22
Texas, Univ. of	3/31/41	Mr. Morehouse, Leeds & Northrup Corp.	Control of Load Frequency on Interconnected Power Systems	38
	4/15/41		Election of officers	19
Tufts Col.	4/17/41		Election of officers	39
Tulane Univ.	3/ 7/41	B. Lavitola, student	Placing the Decimal Point in Slide Rule Computations; election of officers	22
	4/10/41		Motion pictures	15
	4/18/41	Messrs. Basnett and DeLerno, students	An Electronic Circuit for Determining Power Angle Oscillations	39
		Messrs. Haley, Herrod, and Lockwood, students	Remote Control by Radio	
			Joint with New Orleans Section	
Union College	4/29/41	Fred Fisch, Bureau of Traffic and City Planning	Traffic Control Equipment; election of officers	50
Utah, Univ. of	2/14/41	R. W. Sorensen, pres., AIEE	Engineering Horizons, Limited	50
	3/12/41	E. Backman	Development of electrical apparatus in the mining industry	38
	3/24/41		Discussion of plans for Engineering Week exhibits	25
	4/24/41		Election of officers	31
Vermont, Univ. of	1/17/41	R. Marshall, student	Research laboratory of the Sprague Specialties Co.	13
	2/ 7/41	E. R. McKee, counselor	Plans for Engineers' Day	29
	3/ 7/41	H. B. Coburn, student	ROTC summer training camp at Fort Devens	14
	4/11/41		Motion pictures	18
	4/18/41		Election of officers; motion pictures	15
	4/25/41	B. P. Brown, student	A New Television Antenna	15
Virginia Poly. Inst.	4/10/41		Annual smoker	71
	4/17/41		General discussion	41
Virginia, Univ. of	9/24/40	L. A. Quarles, counselor	AIEE activities	25
	10/29/40		Discussion of future activities	17
	11/16/40		Inspection trip to Va. Pub. Serv. Co.	14
	1/29/41	P. Peyton, student	The Advantages of Frequency Modulation in Radio	16
	2/19/41	C. V. Johnson, student	Instrument Landing for Aircraft by Radio	14
Washington State Col.	4/17/41	Capt. Crafton, Military Dept.	Informal talk	36
Washington, Univ. of	3/ 7/41	C. Terrell, Puget Sound Pwr. & Lt. Co.	Notes of an Engineer	57
	4/25/41		Inspection tour of Bremerton Navy Yard	50
Washington Univ.	4/ 7/41		A Resonant Type of Constant Current Regulator	
	4/21/41		Inspection trip through G.E. Lamp Works	17
	4/21/41		Election of officers	26
West Virginia Univ.	4/14/41		Motion pictures	35
Wisconsin, Univ. of	4/17/41	H. Rusch, A. C. Nielsen Co.	Measuring Listening Habits of the American Radio Audience	45
Wyoming, Univ. of	4/ 9/41	S. Phillips, student	Airways Radio Ranges; election of officers	13
	4/22/41		Discussion of future activities	8
	4/28/41		Discussion of Engineers' Open House Display	15

Of Current Interest

Engineers and Selective Service

ALTHOUGH the Selective Service Act provides that no deferment of military service shall be made for occupational groups or groups of individuals in any plant or institution, constructive efforts are being made by Selective Service officials and by many local draft boards to defer from routine military service those men who are necessary in the production of National Defense materials and those students who are preparing themselves for service in defense industries and other activities vital to the national safety. This general subject has been discussed by AIEE President R. W. Sorensen in his messages to the Institute membership published in the March issue (*pages 127–8*), the April issue (*pages 175–7*), and again in this issue (*page 279*). The subject also was discussed by President Harvey N. Davis of Stevens Institute of Technology, Hoboken, N. J., in an address delivered at the AIEE North Eastern District meeting, Rochester, N. Y., May 1, 1941, full text of which is included elsewhere in this issue (*pages 247–50*); and by W. S. Fielding (A'38) in the "Letters to the Editor" columns of this issue.

Studies made by the Bureau of Labor Statistics for the Office of Production Management show that the supply of man power in the following specialized professional fields is "at a dangerously low level":

Chemistry
Engineering
  Civil
  Electrical
  Chemical
  Mining and Metallurgical
  Mechanical

Authorities claim that shortages exist also in other technical fields not yet studied by the Bureau.

SPECIFIC PROVISIONS

Section 5(*e*) of the Selective Service Act specifically authorized the President to provide for the deferment from service and training of those men whose employment in any industry, agriculture, or other endeavors as found by the local board to be necessary to the maintenance of the national health, safety, or interest. Under the authority of this provision the President, in Section XXII of the Regulations, specifically directed local boards to defer all registrants found so to be necessary. In paragraph 352b he calls particular attention to the importance of protecting the National Defense program:

"In determining whether a registrant is a 'necessary man,' the local board shall give due consideration to those registrants engaged in any activity which is essential to the national health, safety, or interest in the sense that a serious interruption or delay in such activity is likely to impede the national defense program."

Local boards must give full weight to this provision in dealing with the claims for occupational deferment of necessary men engaged in activities necessary to the National Defense, including those necessary to defense production. A dual responsibility is imposed upon local boards as they must not only select those who are needed by the armed forces, but must also defer those who are necessary in the production of defense materials. They must take fully into consideration the entire National Defense picture in making that selection or deferment.

A "necessary man" is defined in the Selective Service Regulations as follows:

"A registrant shall be considered a 'necessary man' in industry, business, employment, agricultural pursuit, governmental service, or in any other service or endeavor, including training or preparation therefore, only when all of these conditions exist:

(*a*). He is, or but for a seasonal or temporary interruption would be, engaged in such activity.

(*b*). He cannot be replaced satisfactorily because of a shortage of persons with his qualifications or skill in such activity.

(*c*). His removal would cause a material loss of effectiveness in such activity."

One of the most recent efforts to prevent "necessary men" from being drafted into routine military service consisted of a telegram sent by Brigadier General Lewis B. Hershey, Deputy Director of Selective Service, to all Selective Service State Directors, calling attention to the growing need for skilled industrial workers in our rapidly expanding and vitally important defense industries, and pointing out that it is a basic provision of the Selective Training and Service Act of 1940 that it must be so administered "as not to interrupt, delay, or impede the National Defense program."

"Selective Service regulations," General Hershey said, "were written with respect to occupational deferments to guide local boards and to achieve the following three results: (1) to prevent any unnecessary aggravation of existing shortages of necessary workers in defense activities by broad and intelligent understanding of the magnitude of the Nation's program for defense production; (2) to protect the national industrial-training program from unnecessary interruptions by deferment of individuals when evidence shows that they are 'in training or preparation' for an occupation or employment found to be necessary to the maintenance of the national health, safety or interests, and (3) to anticipate possible exhaustion of pools of highly skilled workers not now employed in defense activities but probably necessary in the near future for the expansion of defense production, when such men, 'but for a seasonal or temporary interruption would be engaged in such defense activity.' "

DEFERMENT OF STUDENTS

The proper classification of students and other registrants in training or preparation constitutes one of the major problems of the Selective Service system. It is provided that a registrant may be deferred if he is found by the local board to be a necessary man in any industry, business employment, agricultural pursuit, governmental service, or any other service or endeavor, or in training or preparation therefore, the maintenance of which is necessary to the national health, safety, or interest. Therefore, students may be deferred where the activity for which they are being prepared is one essential to the national health, safety, or interest. The necessity of providing the required replacements for, and additions to, those men deemed by local boards as being engaged in essential activities, should be considered by local boards in making their determination of individual cases. In determining whether or not a student is a "necessary man," the local boards have been instructed to give due consideration to such factors as the length of time which the student has been pursuing the course in question, his relative progress and standing, and his relative chances for employment in the activity for which he is preparing.

As has been emphasized repeatedly, each individual case is considered by the local boards solely on its own merits and available information; in all instances the final decision is up to the local boards. Therefore, it is vitally important that the local boards be given complete information by or directly in behalf of each individual registrant, if "necessary men" are not to continue to be drafted into services where they can contribute less to the national safety. As Doctor Davis and Doctor Sorensen so appropriately have emphasized, it is the *patriotic duty* of every individual to do everything in his power to aid in his placement where his abilities can be utilized to the fullest possible advantage of the manifold and increasingly vital defense program.

Decentralization the Goal in Locating New Defense Plants

Decentralization appears to be the goal toward which the Government is aiming in locating new factories for the manufacture of defense equipment. Factors that will guide the Government in selecting plant sites were discussed in a recent issue of the *United States News;* excerpts from which follow.

"Well along toward completion is the first $2,500,000,000 batch of Government and privately financed plants. Defense preparations call for at least that much additional construction. . . . Many factories designed primarily for defense probably will become lasting parts of the nation's industrial apparatus when the emergency has passed. Aluminum plants in the South and Northwest, Tennessee Valley Authority power expansion, the Houston area's $17,000,000 steel project are samples of undertakings with long-range utility . . . .

"Over the longer run, regional planning to solve unemployment, farm problems, and urban congestion seems likely to receive attention. The next wave of plant expansion is expected to bring out more clearly decentralization ideas now strongly advocated by key defense planners for military reasons and for building up areas of potential industrial strength. The stupendous job of creating a war industry to out-produce Nazi-dominated Europe may help bring the city and farm closer together . . . .

"In terms of geography, the trend points toward acceleration of industrial shifts into the South and West. For strategic reasons alone, the War Department wants plants out of range of air, sea, and land thrusts at exposed coastal areas . . . . Already preliminary steps have been taken for moving plants inland . . . .

"The first rush for speed piled up orders and new plant construction in existing industrial areas. This tended to increase concentration, rather than redistribute industry . . . . The North and East drew most of the plant construction. Of 273 Government-financed projects costing nearly $1,700,000,000, more than a third went to New York, Ohio, Indiana, Michigan, and Pennsylvania. Seaboard shipbuilding and the placing of aircraft and motor factories near automotive centers partly explains the concentration . . . . But some strides have been taken toward sheltering aircraft, motor, and parts factories in the interior. Munitions plants have started the hike across the mountains. Chemical, aluminum, brass, and miscellaneous supply units have been located at inland points in the initial construction program.

"Government has various means of guiding plant migration. It hands out the orders. Then it does the bulk of the financing, directly or indirectly. Hydroelectric developments, on the TVA pattern, exercise the pull of cheap power. Often a request to industrial management is sufficient. Moreover, Washington now holds the purse strings on large housing expenditures, important for building defense production centers.

"When the search for sites gets down to brass tacks, natural advantages demand consideration. The War Department specifies, for instance, that a site for a smokeless powder plant must satisfy these requirements: (1) large space (about 6,000 acres) free of oil, gas, and water lines; (2) nearby raw materials, including cotton linters or wood pulp, nitric acid, coal, water; (3) facilities for disposal of waste materials; (4) transportation; (5) adequate labor supply; (6) electric power . . . .

"With the passing of the opening drive for production speed, long-range factors of economic planning will get more attention. Plant site experts theorize that planning must be directed toward giving the country the best possible balanced economy—between farm and city, region and region—after the emergency has passed. Concretely this means, in site selection: (1) avoiding communities where defense orders already have soaked up the labor supply; (2) shifting production from cities where housing, transportation, and electric power capacity have been strained; (3) favoring communities with the greatest unemployment; (4) directing the movement of industry south and west."

Fire Defense Discussed by NFPA

Fire defense was the keynote of the 45th annual meeting of the National Fire Protection Association held at the Royal York Hotel, Toronto, Ontario, Can., May 12–16. Among the principal topics discussed were the essential measures to safeguard defense production from interruption by fire due to sabotage, bombing, or the many accidental hazards associated with emergency production.

Protection of cities from possible effects of incendiary bombing and the organization and equipment best suited for the fire defense of American and Canadian cities were reviewed in detail. Special fire problems in aviation, parachute fighting of forest fires, civilian defense plans, and other important topics were discussed by prominent speakers.

Signal Corps Reserve Officers Needed

A thorough canvass of all possible sources to fill the reserve-officer shortage in the Signal Corps is now under way by the United States War Department. Some 1,500 to 3,000 reserve officers are needed in addition to the 1,500 now on duty, the important need being for lieutenants and captains.

Since practically all of the reserve officers in the Signal Corps now are on duty, the War Department announced that "the acute shortage must be met by drawing men with the proper qualifications from other branches of the Army." In this expansion program, preference will be given to all graduate electrical engineers and to those who have experience or training in Signal Corps operation.

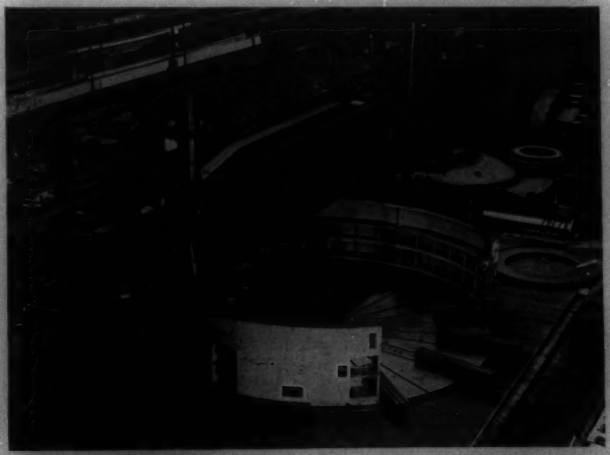
Defense Training Chart

A condensed chart-guide to defense-training opportunities in programs sponsored by Federal agencies has been compiled and issued by the United States Office of Education. The chart-guide, which measures 18 by 23 inches, is entitled "Defense Job Training." It covers 24 training programs including vocational training for persons who have never had a job, advanced training for persons now at work, training of engineers, specialized instruction in radio and at cooks and bakers schools, pilot training (both civil and military), airport attendant preparation, and training for merchant marine ships' officers and crews.

Information which the chart-guide presents to persons interested in a defense job includes: (1) number to be trained or in training in fiscal year 1941; (2) wages in training; (3) fees in training; (4) wages on job; (5) purpose of training; (6) persons eligible; (7) length of courses; (8) where offered; (9) where to apply; and (10) jobs for which training qualifies. Single copies of the chart may be obtained from the Superintendent of Documents, Government Printing Office, Washington, D. C., at five cents each; bulk prices are $2 a hundred, $15 a thousand.

Simplified Stock Sizes of Conductors Proposed

In order to facilitate the national defense program, the adoption of a simplified list of stock sizes of copper conductors has been proposed as a means of reducing unnecessary inventories of copper wire, thus effecting economies and conserving material, ac-



This 40-foot boring mill, recently installed at the East Pittsburgh works of the Westinghouse Electric and Manufacturing Company, is aiding in the construction of large power equipment for the national defense program. This view shows the stator frame of a 30,000-kw water-wheel generator being assembled on the turntable in preparation for machining; for this operation the turntable speed is about 0.34 rpm

cording to an announcement by the National Bureau of Standards, United States Department of Commerce. The proposed simplified list was drafted at a general conference held under the auspices of the Division of Simplified Practice and is now being submitted to the industry, in the form of a Proposed Simplified Practice Recommendation, for consideration and acceptance.

The National Electrical Contractors Association, sponsor of the proposed recommendation, called attention to the fact that appreciable copper tonnages are now tied up in inventories of slow moving sizes, mostly in the upper size range, whose place could be filled more efficiently, from an electrical standpoint, by smaller cables connected in multiple. Therefore, the association suggested the adoption of a simplified list of 19 stock sizes of copper conductors in the range from number 14 (American wire gauge) to 500,000 circular mils, also that sizes larger than 500,000 circular mils be not carried in stock, but should be available only on order.

The general conference, called to consider this suggestion, consisted of representatives of manufacturers, distributors, users (including Governmental agencies) and others interested. After thorough consideration of the relative demand for the various sizes proposed for inclusion in the simplified list, the conferees unanimously decided that the demand for sizes number 5 and number 3 was not sufficient to warrant their retention. With this modification, the suggestions of the sponsoring group were drafted into a recommendation, to become effective for new production for stock, June 1, 1941, subject to approval by the industry.

Radio Manufacturers to Curtail Use of Defense Metals

At a meeting of the Radio Manufacturers Association held in New York, N. Y., April 29, representatives of some 50 of the leading radio manufacturers entered into voluntary formal agreement to curtail sharply the use of aluminum and other metals necessary for National Defense. Use of aluminum alone, it is estimated, will be reduced 75 per cent for normal projected civilian production. The following agreements were adopted unanimously:

1. That the use of aluminum in the manufacture of radio sets be restricted to material for foil in the manufacture of capacitors, and to rotors in variable condensers. Under this agreement aluminum substitutes will be used for coil cans, condenser cans, tube shields, etc., when present aluminum supplies for such numerous radio components are exhausted.

2. Another unanimous industry agreement was that set manufacturers immediately will begin use of variable condensers having steel stators (instead of aluminum), and on and after June 15 will receive and use only condensers having stators of processed steel.

3. Another industry agreement was that set and speaker manufacturers will immediately discontinue purchase of aluminum and also nickel for permanent magnets for sets for domestic and export sale other than battery, portable, and farm sets that operate from batteries, and three-power (a-c-d-c) portable and farm sets. This involves drastic reduction in types and models of small radio sets using P.M. speakers containing aluminum and nickel.

Arrangements also were made for regulation and procedure to insure enforcement of the industry agreements.

New GE Windowless Building

Adding to the growing list of such structures, a one-story windowless building now is under construction at West Everett, Mass., for the General Electric Company, consisting of a main manufacturing section 500 by 400 feet with an attached boiler house, test, and forge shop 80 by 300 feet. It is scheduled for completion in July.

Providing more than five unobstructed acres of production floor space under one roof, the plant will be air conditioned and will be lighted by fluorescent units to an expected level of 50 foot-candles. Two 100-watt 60-inch fluorescent tubes mounted in continuous reflectors extending at frequent intervals the entire length of the building will furnish the illumination. The total lighting load is expected to be 600 kw.

So far the company's expansion program has called for an investment of well over 50 millions of dollars, according to the company's current quarterly report to stockholders. Some factory buildings already are completed, and 14 new buildings and additions are under construction and will be completed this year.

Westinghouse to Operate Navy Plants

The Westinghouse Electric and Manufacturing Company announces that it has been asked by the United States Navy to construct and operate two ordnance plants to manufacture armament equipment for the expanding Navy. The estimated cost is more than $20,000,000, and the buildings will be financed directly by the Navy. Machine tools and manufacturing facilities are expected to cost more than $11,000,000.

One of these plants is to be located at Canton, Ohio, and the other at Louisville, Ky. The Canton plant will consist of four manufacturing buildings, approximately 200 feet wide and 750 feet long, and a cafeteria and office building. They will have a manufacturing area of about 600,000 square feet. The Louisville plant will consist of five buildings, a cafeteria and office building, with a manufacturing area of about 500,000 square feet. All buildings are expected to be completed and ready to begin operations about July 1, 1941.

Educational Program Features Applied Mathematics

Beginning with a summer session which can be continued through the academic year 1941–42, a center where engineers, mathematicians, technicians, and other specialists in defense production can devote their full time intensively to problems of higher mathematics as applied to industry will be set up at Brown University, Providence, R. I., according to a recent announcement by President H. M. Wriston of the university.

Four courses in applied mechanics are to be offered—"partial differential equations," "fluid dynamics," "elasticity," and a seminar for weighing current research problems in elasticity and fluid dynamics. As applied to particular engineering problems, the work of the summer session will deal with highly specialized phases of aeronautics, stresses in machinery, ship construction, ballistics, and the detection of submarines and airplanes.

The program as a whole will become part of the engineering defense-training program of the United States Office of Education and is being aided by a grant of funds from the Carnegie Corporation of New York; no tuition fee will be charged. If the summer session is successful, Brown plans to introduce a full year of similar studies during 1941–42 and to offer fellowships ranging in amounts up to $600.

A maximum of 60 students will be accepted, according to Dean R. G. D. Richardson of Brown's graduate school, who is in charge of the program. All candidates must have already had considerable experience in various branches of higher mathematics, physics, and mechanics, amounting to the equivalent of a year's graduate study. Sessions will begin June 23 and will continue for 12 weeks until September 13. There will be five lectures a week in each course, and at least as much time will be given over to informal conferences.

Electric Power and Defense

"New construction already under way or planned by the electric utilities continues to mount in total and should keep the nation's electric generating capacity well ahead of any increased demand due to the defense program," according to a report in the March issue of Edison Electric Institute *Bulletin*. "At the end of 1940," the report continues, "the total installed capacity exceeded demand by 32 per cent, and the new construction should more than maintain this ample margin.

"Present schedules call for installation in 1941 and 1942 of 6,715,000 kw of new generating capacity, an amount approximately 30 per cent greater than was ever installed in any previous two-year period. Of this total, 6,354,000 kw is scheduled for central-station installation and the remainder in industrial plants.

"New central-station installations amounting to 3,397,000 kw of generating capacity announced for 1941 are being completed as scheduled. The generating capacity scheduled for installation in central stations in 1942 now totals 2,957,000 kw, this amount having been raised 655,000 kw since the first of the year. Additional capacity of 800,000 kw more is already scheduled for 1943, and 620,000 kw for 1944 . . . .

"Electric power output of recent months compared with corresponding figures of peak demands on generating plants reflects the longer working hours of munitions factories. From June to November peak demand increased at about the same rate as energy output. In December, January, and February, however, energy output increased 20 to 25 per cent faster than peak demand. This difference was most pronounced in the New England, Middle Atlantic, and Great Lakes States, in which increased energy output exceeded increased demand by more than 30 per cent. As the defense program advances further into the production stage, with two and three operating shifts becoming the rule in manufacturing

plants, this trend toward greater energy output from existing generating capacity will increase correspondingly."

Telephone Communication and Defense

In a prepared statement presented at the annual meeting of stockholders of the American Telephone and Telegraph Company, President Walter S. Gifford (A'16) called attention to the part the company and its affiliated organizations have been playing in the National Defense program, and to the various appointments of company officials to defense boards and committees of the Government.

Speaking of the additional telephone facilities that the company is being called upon to furnish, President Gifford said in part:

"While we are working at high pressure to give telephone service to the Army and Navy, and to provide other equipment for the two services, almost every other industry in the United States is also working on defense production. We have our part in that because as others increase the tempo of their efforts they inevitably use the telephone more and use more telephones, for the telephone is an instrument of speed and accuracy in modern affairs. And this means that we have a little part in almost every effort toward national defense. A little part in every effort adds up to pretty large figures.

"We have never yet had a net gain of as much as a million telephones in a year—last year's gain of 950,000 was the highest we ever had—but if the present rate of growth should continue throughout the year, we would gain nearly a million and a half telephones—50 per cent more than ever before in one year. In any case an increase of well over a million looks certain."

Government Needs Aeronautical and Mechanical Engineers

The production, development, and testing of aircraft and airplane engines is becoming of increasing importance in the national defense program. Four Government agencies are now seeking qualified engineers who can do the critical investigative and research work connected with the development of faster, safer, and more powerful airplanes. Aeronautical training is especially in demand, although much of the work now being done also requires the services of qualified civil, mechanical, and electrical engineers. The United States Civil Service Commission has announced open continuous examinations in all fields of engineering. Application forms (Form 8) may be obtained at any first- or second-class post office. The application, when properly filed, is rated immediately, and applicants rated eligible may be certified at once to an appointing officer, may be tendered an offer of employment by wire, and may be at work within a week of the time of filing applications.

The Air Corps now employs approximately 400 professional engineers at Wright Field, Dayton, Ohio, where most of the aircraft testing and developmental work of the War Department is concentrated. Many of these engineers in aeronautical and mechanical fields are engaged in checking the latest technical developments in aeronautical research and adapting and applying them to improved military aircraft. The Air Corps is particularly anxious to interest recent engineering graduates and senior students in the many opportunities afforded at Wright Field through the testing and checking of the latest advancements in airplane engine design.

The Navy Department now employs over 165 aeronautical engineers. The Bureau of Aeronautics is charged with responsibility for all that relates to the design, construction, fitting-out, testing, repair, and alteration of naval aircraft and aircraft instruments, equipment, and accessories.

The National Advisory Committee for Aeronautics conducts fundamental research on the problems of flight. The Committee's major research laboratory is located at Langley Field, Virginia, while a second laboratory is partially completed at Moffett Field, California. Current projects involve investigations requiring research in aerodynamics, hydrodynamics, aircraft structures, and aircraft engines; the results of research are available to Governmental agencies and to those units of the aircraft industry that are most concerned. The engineer personnel has increased rapidly in the last six months, and when the new Aircraft Engine Research Laboratory at Cleveland is completed, a still greater number of qualified engineers, particularly aeronautical and mechanical, will be needed. The present personnel includes a total of 340 engineers, of which approximately 50 per cent are aeronautical and 25 per cent are mechanical.

The Civil Aeronautics Authority, which is chiefly concerned with the inspection and development of nonmilitary air transport and airways, also concentrates on the testing and approval of developments in safety devices, instruments, and improved designs for all types of aircraft. Research is conducted at the Bureau of Standards in Washington, D. C., and at the experimental laboratory at Indianapolis; studies are made relative to the extinguishing and prevention of aircraft fires, and an improved system for "blind" landing. At present the Authority is employing over 300 engineers, of which over 20 per cent are aeronautical.

Airplane engine development has not yet reached the stage where little remains to be done. The race to improve aircraft design is now on an international scale and the importance of succeeding in the competition to develop the perfect plane cannot be overestimated. New discoveries are being made almost daily, and events in Europe are furnishing the most exacting trial conditions for the application of new theories to aircraft. Any new discovery may revolutionize some phase of production, if properly applied by qualified engineers who understand the present problems involved in engine and aircraft design, carburetion, cooling, accessories, instruments, fuels, lubricants, etc.

Each of the four agencies mentioned maintains research laboratories at which the major concern is the development of new testing methods to check the efficiency and practicability of current and proposed designs in aircraft and airplane engines. New fuels are being studied in relation to higher speeds, higher altitudes, and longer flights. New types of engines require new lubricants, new superchargers, better carburetion, better bearings. Designs are constantly being improved to allow speedier, more thorough overhauling and easier replacement and repair of worn or damaged parts.

Improvement in the design of aircraft is going ahead rapidly. The engineer is needed to check and test each new feature of design to offset factors of weight and strength against speed and guns and armor plate. Studies are being made of propeller design, engine cowlings, and airfoil design, to combine greatest speed with greatest stability and efficiency. Improved theoretical design must be applied in a usable manner to planes for service under the uncompromising conditions of modern warfare and modern transportation requirements. It is the responsibility of the United States Civil Service Commission to interest qualified engineers in the job to be done, and to furnish the Government agencies with the required personnel to carry on the program.

POSITIONS TO BE FILLED THROUGH CIVIL SERVICE EXAMINATION

Notice of the following positions, which will be filled through civil service examinations, is published here as a service to members of the Institute. Application forms and full information as to requirements for examinations may be obtained from the secretary of the Board of United States Civil Service Examiners at any first- or second-class post office, or from the United States Civil Service Commission, Washington, D. C.

Air Corps Procurement Inspectors. Through an examination announced some time ago, the Civil Service Commission has been seeking experienced men for procurement inspector positions in the Air Corps of the War Department. The Commission has not been able to obtain enough men for these positions. On the contrary, the needs have been extended to other fields than those in the original announcement. Five new fields in which persons may qualify have been added, and the options now are: Aircraft, engines, instruments, parachutes, aircraft propellers, tools and gages, radio, aircraft miscellaneous materials, textiles, fur-lined clothing, and optical. In general, mechanical experience, which may include apprenticeship, is required in the field applied for. For only four options (aircraft, parachutes, propellers, and aircraft materials) need this experience be specifically on aircraft materials. College courses in engineering may be substituted for part of the experience. Applicants will not have to take a written test, but will be rated on their experience and education. For details concerning the amended requirements applicants should consult Announcement No. 6-249 Revised of April 22, 1941. Original appointments will be made at salaries ranging from $1,620 to $2,600 a year. Opportunities for advancement are excellent. Applications may be filed until further notice with the Secretary of the Board of United States Civil Service Examiners at Wright Field, Dayton, Ohio.

Engineering Draftsmen. $1,800 a year; also: chief, $2,600; principal, $2,300; senior, $2,000; and assistant, $1,620 a year. Various optional branches. Applications will be rated as received at the United States Civil Service Commission, Washington, D. C., until December 31, 1941. Announcement previously published (*EE, Feb. '41, p. 91*) has been amended to include the optional branch statistical. There is need particularly for draftsmen qualified in the field of statistics. Information regarding the examination and the other optional branches of drafting for which applications are being received is given in the original announcement.

Industry • • • •

Westinghouse Issues New Magazine

First issue of the *Westinghouse Engineer*, a new quarterly in the field of engineering, published by the Westinghouse Electric and Manufacturing Company, appeared in May 1941. The periodical will be issued in February, May, August, and November, and is distributed to a selected list of engineers and executives of firms using electric power and equipment. It is also available by subscription. It contains no advertising.

According to announcement, the new magazine is planned to offer information on the generation, transmission, and distribution of electric power. Articles will be published on all phases of practical engineering involved in the selection, application, operation, and maintenance of electrical equipment. Charles A. Scarlott is editor, and J. George Adashko (A'34) assistant editor. Among the editorial advisors are R. C. Bergvall (A'24) and Tomlinson Fort (A'27, M'35). Authors represented in the first issue include S. G. Hibben (A'34), J. E. Hobson (A'36), H. V. Putman (A'23, M'32), C. W. Drake (A'20, M'21), and J. S. Parsons (A'27).

Commercial Television July 1 Authorized by FCC

Beginning of commercial television service July 1, 1941, under regulations embodying in substance the standards recommended by the National Television System Committee has been authorized by the Federal Communications Commission. The standards fix the line and frame frequencies at 525 and 30 respectively. Frequency modulation is required for the sound accompanying the pictures. Standards are to be allowed six months of practical test, after which further changes may be considered, particularly with reference to color television.

The Commission's regulations require a minimum broadcast program service of 15 hours a week by commercial television stations, not more than three of which may be under the same control. Action followed the public hearings of March 20–24, 1941 (*EE, Mar.'41, p. 145–7; May'41, p. 241*).

Utilities Add Generating Capacity

Additional generating capacity totaling 3,352,639 kw will be installed in the United States during 1941, according to reported preliminary results of a recent Federal Power Commission survey of the electric utility industry. Compared with 1,877,844 kw reported last year as scheduled for installation during 1940, this figure represents an increase of 78.5 per cent.

The report contains detailed data for scheduled additions to generating plants by privately and publicly owned utilities, subdivided by states and type of prime mover. The geographic summaries show that over 70 per cent of the hydroelectric generating equipment scheduled for installation during 1941 is to be located in the mountain and Pacific areas and is to be added by publicly owned utilities, while a majority of the scheduled steam generating equipment is to be constructed in the Middle Atlantic and East North Central areas by privately owned utilities.

Budgeted expenditures for generating plants of all types for 1941 total $387,517,000 and for all other electric plants $480,692,000, making a grand total of $868,209,000 for all electrical construction expenditures. Of this amount, the budgeted expenditures reported for privately owned utilities total $597,102,000 and those for publicly owned utilities $271,107,000. Comparison of construction expenditures with scheduled additions to generating capacity, by geographical areas, is shown in the accompanying table.

Comparison of Scheduled Additions to Generating Capacity and Electrical Construction Expenditures for 1941 and 1940

(As Reported at the Beginning of Each Year)

Geographic Division	Scheduled Additions to Generating Capacity			Total Electrical Construction Expenditures		
	Kw 1941	Kw 1940	Increase or Decrease (Per Cent)	1941	1940	Increase or Decrease (Per Cent)
UNITED STATES	3,352,639	1,877,844	+ 78.5	$868,208,950	$593,879,533	+ 46.2
New England	148,000	75,557	+ 95.9	45,614,593	34,421,291	+ 32.5
Middle Atlantic	532,566	332,950	+ 60.0	146,364,542	126,616,435	+ 15.6
East North Central	851,684	485,288	+ 75.5	212,107,213	162,305,362	+ 30.7
West North Central	136,017	162,192	- 16.1	52,259,448	35,901,942	+ 45.6
South Atlantic	507,358	445,256	+ 13.9	117,994,253	115,734,755	+ 2.0
East South Central	162,776	102,000	+ 59.6	97,241,025	20,728,151	+369.1
West South Central	90,059	107,546	- 16.3	31,497,201	26,842,812	+ 17.3
Mountain	293,117	29,055	+908.8	24,488,006	12,520,651	+ 95.6
Pacific	631,062	138,000	+357.3	140,642,669	58,808,134	+139.2

Expenditures of Electrical Industries Reported

TOTAL capital expenditures for plant and equipment by 1,354 establishments in the various electrical manufactures and related industries, in 1939, totaled $39,968,347, according to statistics recently announced by the United States Bureau of the Census.

The 1940 Census of Manufactures, covering operations of factories during the previous year, supplied the Census Bureau for the first time with information on such

Expenditures for Plant and Equipment for the Communication Equipment and Related Products Subgroup

	Total for Subgroup		Radios, Radio Tubes, and Phonographs Industry		Communication Equipment Industry	
	Number or Amount	Per Cent of Sub-Group Total	Number or Amount	Per Cent of Industry Total	Number or Amount	Per Cent of Industry Total
Total number of establishments	451	100.0	224	100.0	227	100.0
Number of establishments reporting capital expenditures for plant and equipment	324	71.8	152	67.9	172	75.8
Total value of products	$467,196,654	100.0	$275,870,165	100.0	$191,326,489	100.0
Value of products of establishments reporting expenditures for plant and equipment	441,577,395	94.5	262,892,939	95.3	178,684,456	93.4
Total expenditures for plant and equipment	9,127,979	100.0	4,912,141	100.0	4,215,838	100.0
Expenditures for new construction or major alterations of buildings and other fixed plant and structures	1,348,061	14.8	946,801	19.3	401,260	9.5
Expenditures for new machinery and operating equipment	7,387,359	80.9	3,783,551	77.0	3,603,808	85.5
Expenditures for plant and equipment acquired in a "used" condition from other owners and expenditures for land	392,559	4.3	181,789	3.7	210,770	5.0

Expenditures for Plant and Equipment for Four Industries in the Electrical Machinery Industry Group*

	Electrical Appliances Industry		Insulated Wire and Cable Industry		Automotive Electrical Equipment Industry		Electric Lamps Industry	
	Number or Amount	Per Cent of Industry Total	Number or Amount	Per Cent of Industry Total	Number or Amount	Per Cent of Industry Total	Number or Amount	Per Cent of Industry Total
Total number of establishments	138	100.0	79	100.0	84	100.0	55	100.0
Number of establishments reporting capital expenditures for plant and equipment	92	66.7	60	75.9	47	56.0	38	69.1
Total value of products	$145,696,194	100.0	$120,390,050	100.0	$109,761,620	100.0	$84,827,985	100.0
Value of products of establishments reporting expenditures for plant and equipment	138,824,453	95.3	118,704,552	98.6	105,682,477	96.3	83,488,824	98.4
Total expenditures for plant and equipment	2,278,948	100.0	2,594,507	100.0	2,676,894	100.0	2,646,550	100.0
Expenditures for new construction or major alterations of buildings and other fixed plant and structures	446,778	19.6	436,542	16.8	200,381	7.5	185,410	7.0
Expenditures for new machinery and operating equipment	1,677,080	73.6	2,058,509	79.3	2,449,157	91.5	2,450,327	92.6
Expenditures for plant and equipment acquired in a "used" condition from other owners and expenditures for land	155,090	6.8	99,456	3.8	27,356	1.0	10,813	0.4

*Each of these industries has the status of a subgroup.

Expenditures for Plant and Equipment for the "Electrical Equipment for Industrial Use" Subgroup*

	Total for Subgroup		Wiring Devices and Supplies		Carbon Products for the Electrical Industry, and Manufactures of Carbon or Artificial Graphite		Electrical Measuring Instruments		Generating, Distribution and Industrial Apparatus and Apparatus for Incorporation in Manufactured Products	
	Number or Amount	Per Cent of Subgroup Total	Number or Amount	Per Cent of Industry Total	Number or Amount	Per Cent of Industry Total	Number or Amount	Per Cent of Industry Total	Number or Amount	Per Cent of Industry Total
Total number of establishments	727	100.0	146	100.0	31	100.0	59	100.0	491	100.0
Number of establishments reporting capital expenditures for plant and equipment	494	68.0	111	76.1	21	67.7	33	55.9	329	67.0
Total value of products	$624,940,790	100.0	$94,305,273	100.0	$18,375,580	100.0	$41,797,495	100.0	$470,462,442	100.0
Value of products of establishments reporting expenditures for plant and equipment	601,794,905	96.3	90,702,038	96.2	15,798,092	86.0	40,073,943	95.9	455,220,832	96.8
Total expenditures for plant and equipment	16,733,489	100.0	1,936,535	100.0	648,334	100.0	1,327,629	100.0	12,821,091	100.0
Expenditures for new construction or major alterations of buildings and other fixed plant and structures	2,548,402	15.2	247,628	12.8	226,623	34.9	297,430	22.4	1,776,721	13.9
Expenditures for new machinery and operating equipment	13,691,920	81.8	1,607,955	83.0	351,190	54.2	1,027,947	77.4	10,704,828	83.5
Expenditures for plant and equipment acquired in a "used" condition from other owners and expenditures for land	493,167	3.0	80,952	4.2	70,421	10.9	2,252	0.2	339,542	2.6

*The four industries included are: wiring devices and supplies, carbon products for the electrical industry, and manufactures of carbon or artificial graphite, electrical measuring instruments, and generating, distribution, and industrial apparatus for incorporation in manufactured products, not elsewhere classified.

Expenditures for Plant and Equipment for the Electrical Products Not Elsewhere Classified Subgroup*

	Total for Electrical Products Not Elsewhere Classified Subgroup		Batteries, Storage and Primary (Dry and Wet) Industry		X-Ray and Therapeutic Apparatus and Electronic Tubes Industry		Electrical Products Not Elsewhere Classified Industry	
	Number or Amount	Per Cent of Subgroup Total	Number or Amount	Per Cent of Industry Total	Number or Amount	Per Cent of Industry Total	Number or Amount	Per Cent of Industry Total
Total number of establishments	480	100.0	221	100.0	84	100.0	175	100.0
Number of establishments reporting capital expenditures for plant and equipment	299	62.3	138	62.4	50	59.5	111	63.4
Total value of products	$174,576,656	100.0	$117,582,712	100.0	$17,945,038	100.0	$39,048,906	100.0
Value of products of establishments reporting expenditures for plant and equipment	162,466,547	93.1	113,117,878	96.2	16,702,544	93.1	32,646,125	83.6
Total expenditures for plant and equipment	3,909,980	100.0	2,319,018	100.0	294,045	100.0	1,296,917	100.0
Expenditures for new construction or major alterations of buildings and other fixed plant and structures	651,940	16.7	371,723	16.0	106,905	36.4	173,312	13.4
Expenditures for new machinery and operating equipment	3,127,865	80.0	1,893,666	81.7	171,952	58.5	1,062,247	81.9
Expenditures for plant and equipment acquired in a "used" condition from other owners and expenditures for land	130,175	3.3	53,629	2.3	15,188	5.1	61,358	4.7

*The three industries included are: batteries, storage and primary (dry and wet), X-ray and therapeutic apparatus and electronic tubes, and electrical products not elsewhere classified.

expenditures. Manufacturers were requested to report charges to capital account for new depreciable assets at cost value.

Expenditures for new machinery and operating equipment constituted the largest part of the capital outlays reported, with a total of $32,842,217. Outlays for new construction or major alterations of buildings and other fixed plant and structures totaled 5,817,514, while expenditures for plant and equipment acquired in a "used" condition from other owners and expenditures for land totaled $1,305,616.

The establishments reporting plant and equipment expenditures accounted for more than 95 per cent of the value of products made in the electrical manufactures and related industries. The total value of products reported by the 2,014 establishments grouped in the several industries was $1,727,389,949. Of this total, the 1,354 establishments reporting expenditures for plant and equipment, produced goods valued at $1,652,599,153. Data upon expenditures by the various classifications of electrical industries are given in the accompanying tables.

Honors • • • •

Award Established by Engineering Societies of New England

A new honor in the field of engineering, the "New England Award", presented this year for the first time, has been established by the Engineering Societies of New England, Inc. The award "is to be made not more than once a year to a living engineer, resident in New England, who by outstanding achievement has merited recognition of his work and character by his fellow engineers of the New England States." The recipient will be chosen from nominations of the constituent societies of the Engineering Societies of New England, Inc., and from the co-operating organizations allied with the Societies. The award was made this year to W. H. Pratt (A'02, F'13) retired consulting engineer, General Electric Company, Lynn, Mass. A biographical sketch of Mr. Pratt appears on page 294.

W. L. Batt Awarded 1940 Gantt Medal

The Henry Laurence Gantt Memorial Gold Medal for 1940 was awarded to William Loren Batt, deputy director, production division, Office of Production Management, Washington, D. C.

The medal is awarded annually for "distinguished and liberal-minded leadership in the art, science, and philosophy, of industrial management in both private and public affairs". It was established in 1929 through a fund raised by a group of friends of the late Henry Laurence Gantt, to commemorate his achievements in the field of industrial management. Selection of the recipient is made by a board made up of representatives of the American Society of Mechanical Engineers and the Institute of Management. First award of the medal was made to Mr. Gantt posthumously, in 1929.

A native of Salem, Ind., Mr. Batt received the degrees of mechanical engineer in 1907, and doctor of engineering in 1933, from Purdue University. He has been associated with the SKF Industries, Inc. and its predecessor the Hess-Bright Manufacturing Company since 1907, and has been president of SKF since 1923. He is a past president of the Society of Mechanical Engineers. Mr. Batt is chairman of the Business Advisory Council of the United States Department of Commerce; chairman of the division of engineering and industrial research of the National Research Council; chairman of the board of the American Management Association; and president of the International Committee on Scientific Management. He has been decorated twice by King Gustav V of Sweden for his work in promoting commercial relations between Sweden and the United States.

Other Societies •

NFPA Creates Endowment Fund

"To help perpetuate a program for the reduction of loss of life and property by fire" an endowment fund for the National Fire Protection Association has been created by recent action of the board of directors. The purpose of the fund is to enable the Association to undertake worthwhile research projects and other activities not permitted under present budget limitations. It is proposed that the fund shall be derived from gifts and from bequests in wills by members of the NFPA and others interested in furthering its objectives.

National Science Fund Established

"To receive and administer gifts for the advancement of science", a National Science Fund has been set up by the National Academy of Sciences, F. B. Jewett (A'03, F'12), president, announced recently. The fund has been organized as the result of a three-year study of the present sources of financial support for fundamental research in science by a committee under the chairmanship of Doctor A. F. Blakeslee, of the Carnegie Institution, Washington, D.C. The study disclosed an urgent need of new resources of revenue, to supplement and replace sources diminished through the depression and other economic changes. The Fund will be directed by a joint board of 12 lay members and 20 scientists. Doctor William J. Robbins, director of the New York Botanical Garden, has been made acting chairman.

Future Meetings of Other Societies

American Association for the Advancement of Science. 108th meeting, June 23–28, 1941, Durham, N. H.

American Chemical Society. Annual meeting, September 8–12, 1941, Atlantic City, N. J.

American Physical Society. 243d meeting (Pacific Coast), June 18–20, 1941, Pasadena, Calif.

243d meeting, June 20–21, Providence, R. I.

American Society for Testing Materials. 44th annual meeting, June 23–27, 1941, Chicago, Ill.

American Society of Civil Engineers. Annual convention, July 23–25, 1941, San Diego, Calif.

American Society of Heating and Ventilating Engineers. Semiannual meeting, June 16–19, 1941, San Francisco, Calif.

American Society of Mechanical Engineers. Semiannual meeting, June 16–20, 1941, Kansas City, Mo.

Association of Iron and Steel Engineers. Annual convention, September 23–26, 1941, Cleveland, O.

Canadian Electrical Association. Annual meeting, June 25–27, 1941, Seignory Club, Quebec, Canada.

Illuminating Engineering Society. Convention, September 22–25, 1941, Atlanta, Ga.

Institute of Radio Engineers. Summer convention, June 23–25, 1941, Detroit, Mich.

Society for the Promotion of Engineering Education. 49th annual meeting, June 23–27, 1941, Ann Arbor, Mich.

Letters to the Editor • • •

INSTITUTE members and subscribers are invited to contribute to these columns expressions of opinion dealing with published articles, technical papers, or other subjects of general professional interest. While endeavoring to publish as many letters as possible, Electrical Engineering reserves the right to publish them in whole or in part or to reject them entirely. Statements in letters are expressly understood to be made by the writers; publication here in no wise constitutes endorsement or recognition by the AIEE. All letters submitted for publication should be typewritten, double-spaced, not carbon copies. Any illustrations should be submitted in duplicate, one copy an inked drawing without lettering, the other lettered. Captions should be supplied for all illustrations.

Total Security—a Challenge

To the Editor:

Are engineers to offer more than technical ability for the welfare of the United States? The many comments in the April and May issues of ELECTRICAL ENGINEERING seem to prove without question that perhaps for the first time we, as a class, are accepting the responsibilities not only of machines but of directing our basic progress in defense.

Mr. Skinker, on page 194 of the April issue, has boldly challenged the inventiveness of all of us in making suggestions, small as they may seem, to safeguard production as a whole. Certainly today is no time for shyness because if all but one out of a thousand ideas are foolish, still a single plan is invaluable.

Those of us fresh from college are painfully aware of one handicap in the widely accepted plan to condense the time required to graduate: many students depend upon summer times to earn enough for further studies. What can circumvent this diffi-

culty is questionable. Perhaps our industries can arrange to give practical experience to such students in the summer period so as better to prepare students for positions after graduation, and even shorten the time needed for such study in the university.

To help stimulate thinking I would like to offer a few suggestions for discussion:

1. Perhaps now is the time to think of safeguarding valuable operating drawings and records by keeping duplicate prints where damage from fire, etc., to the originals cannot hinder production.

2. Many records could be preserved by photographing in miniature on roll film; maps with color codes might be photographed in Kodachrome and provision made for projecting the maps through a frosted translucent screen for inspection in emergency, if the originals should be lost.

3. The fire protection of automatic CO_2 extinguisher systems so carefully applied to plants might well be installed near essential prints and other perishable equipment. At the same time some of our antique wooden cabinets may be retired honorably from long service, and fire-resistant units substituted.

4. Better to acquaint engineers with the many night courses now offered, possibly our organ could act as a clearing house of such data, indicating local references. The few companies not offering such information to their technical employees ought to join the majority.

5. Maybe each of us in his own small way can inform his acquaintances of the genuine shortage of trained men, thus contributing to the end where every man may work to the peak of his ability and limit of his knowledge. Efficiency in the utilization of skilled men will be the backstay of defense in the testing period facing us.

WILLIAM C. URLOVIC (Enrolled Student)

(Electric department, Pacific Gas and Electric Company, San Francisco, Calif.)

Engineers and the Draft

To the Editor:

More than six months ago the first draftees filled out their questionnaires and were classified. On the whole, most of us will agree that the workings of the Selective Service Act during that time have been satisfactory. Some 4,000,000 men between the ages of 21 to 35 inclusive have been classified, and, according to a recent news report, 402,000 are serving in the military forces.

How have electrical engineers fared in the draft? Of the 18,000 members of the AIEE, one-third will receive draft questionnaires. Considering the whole electrical-engineering group of about 60,000* the draft includes an aggregate of 20,000 electrical engineers. If the draft law is revised to include only those from ages 21 to 26 inclusive, 8,000 electrical engineers still will receive questionnaires.

Draft boards throughout the country are now in the process of assigning these 20,000 engineers to classes I, II, III, and IV and their subdivisions. Only those classed in *IA* as "fit for general military duty" are being sent to training camps. Class *IIA* includes those deferred because of occupation, who otherwise would be placed in class *IA*. Those with dependents are placed in class *IIIA*, while class *IVA* includes miscellaneous deferments.

Of the 20,000 engineers receiving questionnaires, many will be placed in class *IIIA* and can continue in their jobs without interruption. A large number, however, are single, without dependents, and, unless recognition is given to their occupational status, will be called to serve a year in camp. If this happens, the loss of trained engineers at a time when they are greatly needed will hinder rather than help the defense program.

Is such recognition being given? The answer varies widely with different draft boards. Some have been quick to see the importance of the engineer in his job, and to grant occupational deferments. Others, however, do not appear to see how electrical engineering has anything to do with defense.

One board, situated in a western state, gave a two months' deferment to a young engineer who was testing equipment, of which fully one-third was marked "for defense". When his two months' deferment expired, a second request brought him a second deferment—for two months. Considerable correspondence, in addition to the regular request for deferment which outlined his duties, was needed to show the board the importance of this test engineer's job.

Another draft board, in a midwestern state, delayed two months over the questionnaire of another test engineer, until the deferment request, also complete in its description of the man's duties was supplemented with a two-page letter. The board then stated that it had delayed classifying the man until further information was obtained as to his duties in the defense program. Since that information had now been supplied, the board place him in class *IIA* for six months, with privilege of renewal.

Still another draft board, this time in the south, rejected the occupational deferment claim filed by one of these young test men, even though he was testing Navy turbines. After further correspondence, the board reconsidered and placed him in class *IIA* for six months, the maximum period of deferment.

A New York draft board placed in class *IA* a graduate chemist who is developing a domestic synthetic substitute for an imported material whose source is threatened. Although newly engaged, he had previous experience to make him immediately effective on his job. These facts were clearly stated on the deferment request, which was supplemented by the chemist's personal appearance before the board. Nevertheless, he was placed in *IA*. He then presented his case to an appeal board which, up to the present, has not acted on it.

These examples are not cited to criticize the work of the draft boards. The members of these boards are, in the writer's opinion, sincere private citizens acting from patriotic motives. They are faced with difficult decisions. Their mistakes in most cases have been caused by a lack of sufficient general information.

Many employers likewise do not have sufficient perspective to act wisely on the question of deferments. One of the most promising young mechanical engineers of the writer's acquaintance recently was drafted and is doing routine service. He could be doing effective mechanical engineering work in an industrial company or in naval architecture. Evidently his employer failed to act, nor did the draft board voluntarily give him a deferred status, although it had the power to do so.

In another instance an electrical engineer was employed by a steel company on maintenance engineering when he received his questionnaire. The plant was in a period of expansion and the services of the maintenance organization were needed. The importance of the steel industry to the rearmament program is obvious. The employer did not ask for deferment and the young man was placed in class *IA*. Later he obtained similar engineering work with another company. Upon request of his new employer, the draft board re-classified him, placing him in *IIA*.

It is not always the draft board or the employer which lacks information. In some cases, the individual is unaware of his obligation under the Selective Service Act. An electrical engineer with three years training had left college and was employed in industry. When he received his questionnaire he failed to inform his employer, although asked to do so. No deferment was requested until the employer learned of the situation ten weeks later. The draft board then rejected the claim, stating that the time to appeal the classification had expired.

That a shortage of trained engineers exists is evidenced in many ways. Industries are expanding their quotas for young engineers. Recruiting at the colleges is more active than ever. The placement bureaus report a steady demand for engineers during the past year. The United States Office of Education has recognized the lack of graduate engineers and has formed a Bureau of Engineering Defense Training. Courses of college grade, 12 weeks in duration, are being offered this summer at many colleges to train men in machine design, production engineering, metallurgy, material testing and inspection, chemistry, and other subjects.

Such programs underline the fact that it is a mistake to allow trained men to be drafted as privates when there are not enough skilled engineers to meet defense production requirements.

Some professional groups have already recognized the problem. The New York Academy of Medicine has gone on record as urging deferment of students in approved medical schools and of medical graduates working as internes. The American Chemical Society since last October, has been educating its members and the public through its periodicals and in the newspapers concerning the lack of trained chemists. Other chemical publications have featured similar articles. Through such publicity, misapplications of technical personnel, due to lack of sufficient information by employers, by the individual himself, or by the draft boards, will be eliminated.

In undertaking such a program it must be recognized that the Selective Service Act provides that:

"No deferment from training and service shall be made in the case of an individual except upon the basis of the status of such individual, and no deferment shall be made of individuals by occupational groups or groups of individuals in any plant or institution."

While each individual case must be considered on its own merits, better decisions will be made if everyone appreciates the

* THE PROMISE OF TOMORROW. Walter E. Myer and Clay Moss, Civic Educational Service, Washington, D. C.

increasing demand for additional trained engineers and realizes the difficulty of locating adequate replacements for those who are drafted.

It is not within the scope of this letter to discuss methods by which the quotas for *1A* men will be met. So far the draft boards have been able to solve that problem. One Massachusetts draft board reported in April that it had classified only 37 per cent of the young men who had registered, and had a reserve supply of *1A* men not yet inducted into service. Also, only those in class *1A* are being called for duty. Men in class *1B*, "fit for limited military service", are not being inducted. This class constitutes from 8 to 24 per cent of those examined by the boards. Colonel Samuel J. Kopetzky, chief of the medical division of the New York City Selective Service, states that many of the *1B* men in his area have easily remediable defects and suggests that steps could be taken to make this group fit for service.

Many engineers hold commissions in the Officers Reserve Corps. Some already are serving in the Army; others will be called to duty during the coming months. Engineers are also members of the Naval Reserve and National Guard. As a group they are well represented in the armed forces of the United States.

If skilled engineers are drafted as privates, it will not be the fault of the Selective Service organization, which has expressed its approval of deferring skilled employees, in newspaper releases which point out that at present production must have priority.

By this time the solution to the draft problem is probably obvious. It requires education by professional engineering societies and other groups which will reach employers, individual engineers, and the draft boards. Such education should be national in scope. It should appear in engineering journals and in newspapers. The question should be a topic of discussion at conventions.

A program of this type should continue until it obtains recognition. It should be endorsed by national engineering organizations and by educational institutions whose prestige will carry weight with the general public.

Such an undertaking will be a real service. It will clarify the task of the draft boards; employers of technical men will be benefited; and the individual engineer will be allowed to remain on his job where, at present at least, he is most effective in the defense program.

W. S. FIELDING (A'38)

(Pittsfield, Mass.)

Books Received •

"Student and Employee Safety in Colleges and Universities". Published by the National Safety Council, Inc., this booklet deals with safety problems encountered in American educational institutions, a field where there are no laws making administrators responsible for safety of students. Contents of the booklet include: Organization to prevent accidents; fundamentals of accident prevention; inspecting for safety; standards for safety; safety in athletics; and campus traffic safety. The booklet contains 82 pages and is illustrated. Copies may be obtained at $1.00 each from the National Safety Council, Inc., 20 North Wacker Drive, Chicago, Ill.

"The Wheeler Project". The second Tennessee Valley Authority technical report deals with planning, design, and construction of the Wheeler Project on the Tennessee River. The first report was "The Norris Project", published in 1939. The book includes a description of the initial social and economic investigations necessary for the project; discussion of the designs of lock, dam, and powerhouse; a study of access roads and housing for employees; description of construction methods and reservoir adjustments; summary of initial activities; and an analysis of construction costs. Appendixes contain a statistical summary of the physical features of the project, copies of the reports of engineering and geologic consultants and summaries of special tests. Copies of the 362-page illustrated report may be obtained from the Superintendent of Documents, Washington, D. C., price $1.00 per copy.

"Insulation of Electrical Apparatus". Planned as a textbook on insulation for electrical engineering students interested in design and operation of power machinery, this study by Douglas F. Miner is a survey of several phases of the problems of dielectrics. It contains a résumé of the essential concepts of the nature and behavior of dielectrics; a description and comparison of insulating materials; discussion of the practices in application of insulation to the major types of power apparatus; and a description of testing methods and equipment. Appendixes contain tables and curves showing properties of certain classes of insulation. McGraw-Hill Book Company, New York, N. Y.; 452 pages, illustrated, price $5.00.

The following new books are among those recently received at the engineering Societies Library. Unless otherwise specified, books listed have been presented by the publishers. The Institute assumes no responsibility for statements made in the following summaries, information for which is taken from the prefaces of the books in question.

ADVANCED ELECTRICAL MEASUREMENTS. By W. C. Michels. Second edition. D. Van Nostrand Company, New York, 1941. 347 pages, illustrated, 9 by 5½ inches, cloth, $3.50. In addition to standard methods and apparatus of the electrical laboratory, covers the application of instruments essentially electrical in character to the measurement of other physical quantities. Among alternative methods or instruments the author describes those which he has found satisfactory from personal experience. New edition is thoroughly revised, particularly in regard to application of electronic methods.

ANALYTICAL DESIGN OF HIGH-SPEED INTERNAL-COMBUSTION ENGINES. By F. M. Cousins. Pitman Publishing Corporation, New York and Chicago, 1941. 226 pages, diagrams, etc., 9 by 6 inches, cloth, $3.50. After reviewing thermodynamic cycles, the author proceeds to a detailed study of the dynamics of high-speed engines. In-line, V-type, radial, and offset cylinder engines all are considered in the discussion of engine balance and the analysis and design of cams, crankshafts, etc. Analysis has been restricted to the calculus and simple harmonic theory. Bibliography.

APPLIED HEAT TRANSMISSION. By H. J. Stoever. McGraw-Hill Book Company, New York and London, 1941. 226 pages, illustrated, 9½ by 6 inches, cloth, $2.50. Aims to provide in readily usable form for engineers some of the more important data on heat transmission and to describe some of the common types of equipment for transferring heat and kinds of insulation used in industry. Charts and tables for determining convection coefficients and values of the pressure drop are included.

THE CHEMICAL ACTION OF ULTRAVIOLET RAYS. By C. Ellis and A. A. Wells; revised and enlarged edition by F. F. Heyroth. Reinhold Publishing Corporation, 1941. 961 pages, illustrated, 9½ by 6 inches, cloth, $12.00. Advances in the field of photochemistry in the 16 years since this monograph first appeared have necessitated rewriting and expansion in the new edition. Part one describes the types of apparatus available for producing ultraviolet rays; part two deals with photochemical reactions; part three with the uses of photochemistry in industry; and part four with applications in biology. Bibliography.

COMMERCIAL REFRIGERATION AND COMFORT COOLING. By S. C. Moncher. Nickerson and Collins Company, Chicago, Ill., 1940. 109 pages, illustrated, 9½ by 6 inches, cloth, $1.50. A brief, nonmathematical description of commercial refrigeration as used in shops and restaurants, with emphasis on engineering methods in common use. Intended for those with a general knowledge of the field, who wish definite information upon equipment and its installation. Air conditioning is considered briefly.

DESIGN OF SHADING COILS FOR ALTERNATING-CURRENT ELECTROMAGNETS. By L. A. Doggett and F. S. Veith. Pennsylvania State College Engineering Experiment Station Bulletin No. 52, State College, Pa., 1940. 24 pages, illustrated, 9 by 6 inches, cloth, $.50. Contains complete instructions for the design of a shaded-coil a-c electromagnet, with special reference to minimizing vibration by proper selection of shading-coil resistance. Short bibliography.

ELECTRIC AND MAGNETIC FIELDS. By S. S. Attwood. Second edition. John Wiley and Sons, New York, 1941. 480 pages, diagrams, etc., 9½ by 6 inches, cloth, $4.50. Presents the fundamentals of electricity and magnetism in a manner intended to co-ordinate elementary college study of mathematics, mechanics, and physics with the professional studies of the last two college years. Revised to provide background for courses in electronics, electrical design, and machinery. The four parts cover, respectively, the electric field, the magnetic field, the ferromagnetic field, and combined fields.

ELEKTRISCHE KIPPSCHWINGUNGEN, WESEN UND TECHNIK. (Physik und Technik der Gegenwart, volume 8.) By H. Richter. S. Hirzel, Leipzig, 1940. 154 pages, diagrams, 9 by 6 inches, paper, 10 rm. Describes the nature, method of generation, transference and intensification, and methods for technical analysis of relaxation oscillations in electrical apparatus. The final chapter indicates applications to electrotechnical and other technological fields. Bibliography.

GENERATING STATIONS, ECONOMIC ELEMENTS OF ELECTRICAL DESIGN. By A. H. Lovell. Third edition. McGraw-Hill Book Company, New York, 1941. 471 pages, illustrated, 9 by 6 inches, cloth, $4.50. Applies economic principles to design of generating stations and transmission systems, considering selection and application of apparatus, proportioning of details of the assembly, balancing of initial and subsequent costs, and related topics. New edition, revised in the light of recent developments. Illustrative problems.

INDUSTRIAL RELATIONS DIGESTS: I. THE ORGANIZATION OF A PERSONNEL DEPARTMENT. II. THE EMPLOYMENT DIVISION. III. REORGANIZATION OF HOUR SCHEDULES. Princeton University, Industrial Relations Section, Princeton, N. J., 1941. Each 7 pages, tables, 10 by 7 inches, paper, $0.30 each. Three pamphlets prepared for use in companies facing rapid expansion because of defense orders. They are based on information received currently from a large number of representative companies. A more complete study of the subject matter of III is in preparation.

MATHEMATICS FOR ENGINEERS. By R. W. Dull. Second edition. McGraw-Hill Book Company, New York and London, 1941. 780 pages, diagrams, etc., 8½ by 5½ inches, cloth, $5.00. A review of the phases of mathematics especially important in engineering, intended as a practical reference work or a text for private study. The chapter on the slide rule has been extended in this edition.

AMERICAN PLANNING AND CIVIC ANNUAL 1940. Edited by H. James. American Planning and Civic Association, Washington, D. C., 1940. 278 pages, illustrated, 9½ by 6 inches, cloth, $3.00. The papers collected in this volume constitute a record of recent civic advance in the fields of planning, parks, housing, and neighborhood improvement. About half the material was prepared especially for the Annual; the remainder consists of the principal papers delivered at the 1940 National Conference on Planning and the 19th National Conference on State Parks, 1940.

Transactions Section

Preprint of Corresponding Pages From the Current Annual Transactions Volume

Any discussion of these papers will appear in the June 1941 "Supplement to Electrical Engineering—Transactions Section"

Experience With Preventive Lightning Protection on Transmission Lines

S. K. WALDORF
MEMBER AIEE

Synopsis: Footing resistances for transmission line towers must be low for good operation, but it appears that no benefit results from reducing them below a certain limiting value characteristic of a given construction. This is because flashover can apparently be caused not only by excessive footing resistance drop, but also by the reactive drop accompanying rapid rates of current rise when tower currents are large.

The records seem to show that overhead ground wires provide better shielding than has been believed. Overhead ground wires and tower footing resistances co-ordinated with line insulation provide preventive protection which is highly efficient.

Operating experience indicates that lightning outages can be predicted fairly well from simple probability calculations.

I. Introduction

THE art of protecting transmission lines against lightning has advanced considerably in the last decade, but there are some phases of the problem which are still obscure. In analyzing the experience of the Pennsylvania Water and Power Company, which operates steel tower transmission lines at 66 to 220 kv, certain trends have appeared which are believed to be significant. It is the purpose of this paper to bring these findings to the attention of those interested in lightning protection in order that the apparent trends may be widely investigated and their validity established or disproved. The interpretation of results as given here, therefore, in no sense should be considered as final, but only as bases for further study.

Paper 41-36, recommended by the AIEE committee on power transmission and distribution, and presented at the AIEE winter convention, Philadelphia, Pa., January 27-31, 1941. Manuscript submitted July 23, 1940; made available for preprinting December 10, 1940.

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1. For all numbered references, see list at end of paper.

Preventive lightning protection for transmission lines, as the term implies, is designed to prevent flashovers entirely as contrasted to remedial measures which are designed to minimize the effects of lightning. In this paper, preventive lightning protection is used in a special sense as the designation for the mounting of overhead ground wires on the same steel towers as the power conductors and the co-ordination of tower footing resistances with line insulation. Tower footing resistances on the lines referred to here have been almost exclusively reduced by the installation of buried counterpoise conductors of various lengths and number.

II. Extent of Experience

The Pennsylvania Water and Power Company first began to try preventive lightning protection on its transmission lines in 1931 with the construction of the Safe Harbor-Westport 220-kv line.[1] Since then two new lines have been constructed and five old ones improved using the same basic principles, but with variation in details.

In 1934, surge-crest ammeter links[2] were installed on the Safe Harbor-Westport-Takoma 220-kv line and since then their use has been gradually expanded until in 1939, 2,279 transmission towers on 318 miles of line have been equipped. These devices have permitted a relatively close check to be made of the efficiency of the lightning protection.

Surge-crest ammeter links have also been placed on 21 banks of 66-kv lightning arresters, two banks of 132-kv arresters, and one bank of 220-kv arresters.

III. Distribution of Current in Tower Members

For several years, there has been a total of 87 towers equipped with a pair of surge-crest ammeter links on each of the four corner or leg members of each tower. Since 1934, 209 sets of records have been obtained from these installations, of which 98 records are from towers believed to have been struck by lightning or adjacent to struck spans. The purpose of these observations has been to determine the error entering into the assumption that the tower current is four times the current in one corner leg.

The results of this study are given in table I. The sum of the four indications in the corner legs has been taken as the approximately correct tower current. The deviation from it of four times each of the four individual leg currents has been obtained. The deviations for each group of tower records in 5,000-ampere increments of tower current have been averaged in table I.

Although relatively few readings have been obtained when the tower currents were of the larger magnitudes, from table I it appears that the indications obtained on towers having a bracket on only one leg can be assumed to be fairly good approximations when the currents are in

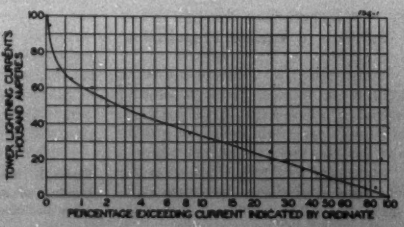


Figure 1. Distribution of 1,201 currents measured in towers believed struck by lightning (1934-39)

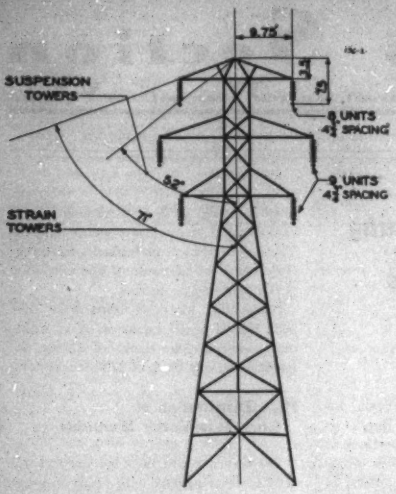


Figure 2. Minimum shielding zones required of single overhead ground wire on suspension and strain towers of the Holtwood–Coatesville 66-kv line

the upper range, that is, greater than about 40,000 amperes.

In 45, or 22 per cent of the 209 sets of observations, the magnetic links on all legs of a tower did not have the same polarity of magnetization. It is believed that records of this type are due to successive strokes of opposite polarity, occurring either close together or with an appreciable elapsed time between them. As they have been found only in the lower current ranges, it is not likely that the large deviations in indication which they cause greatly affect the analyses given here.

It has been suggested that tower currents, as taken from records obtained in the four corner leg members of a tower, be multiplied by a factor ranging from about 1.3 to 2 to account for the current passing through the cross braces of the tower.[3] Because of the uncertainty of the value of the factor,[4] and the unequal distribution of lightning current in tower legs as shown in table I, none has been used in the data reported here.

IV. Distribution of Tower Currents of Various Magnitudes

In the period of 1934–39, a total of 1,201 tower currents has been recorded where it is believed that lightning struck. The tower current in each case was recorded as four times the current indicated in one of the four tower legs, or as the sum of the four indicated leg currents, depending upon the number of SCA links installed at the respective tower. The data have been plotted in figure 1.

V. Distribution of Lightning Strokes Along Lines

The records show that the 1,201 strokes which have terminated on the lines of the system have been well distributed. For instance, on the Safe Harbor-Perryville 132-kv line there were not over three consecutive towers which were not struck during the five-year period of the study. On the Safe Harbor-Westport-Takoma 220-kv line where the stroke records have been kept for six years, five is the maximum number of consecutive towers where no strokes have occurred. Although a considerable length of a line may not be struck during the first observation year, in general, it has been found that during succeeding years the maximum length of unstruck line is reduced to a few spans.

VI. Lightning-Stroke Frequency

In table II, the variations in frequency of occurrence of lightning are apparent. It will be noticed that the number of recorded strokes to a line will vary in the ratio of almost as much as three to one from year to year. During a year when the number of strokes to one line may be relatively high, those on another may be very low, as for instance, in the years 1935 and 1938. The average number of strokes per hundred miles of line per year is 126 for rights-of-way having only one line. This value cannot as yet be considered as final because the averages for the individual lines still deviate from it by as much as 29 per cent.

VII. Flashovers

Examination of the lightning current records of the Holtwood-Coatesville 66-kv line obtained during the three years before the installation of counterpoise re-

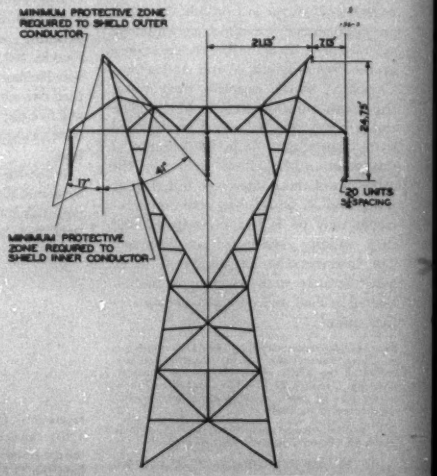


Figure 3. Minimum shielding required of overhead ground wires on 220-kv towers

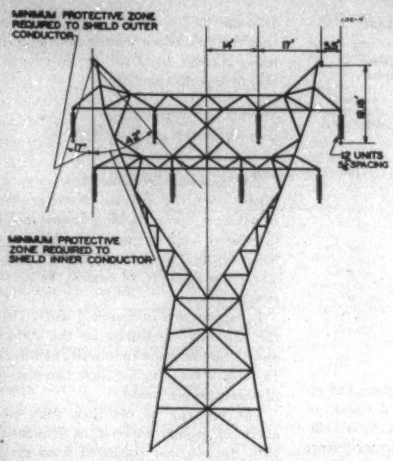
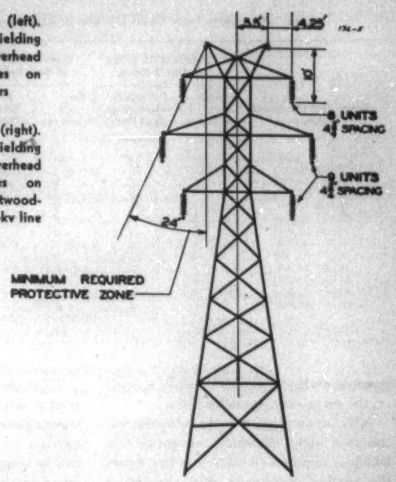


Figure 4 (left). Minimum shielding required of overhead ground wires on 132-kv towers

Figure 5 (right). Minimum shielding required of overhead ground wires on towers of Holtwood-York 66-kv line



veals no regular behavior. There were 21 single- and double-circuit tripouts during 1935, 20 during 1936, and 17 during 1937. The individual effects of poor grounding, insulation, and shielding are indeterminate from the data. However, after the installation of counterpoise and the improvement of insulation, the relative importance of the several protection factors became more apparent. The Holtwood-Coatesville line is the only line of the company on which surge-crest ammeter links were placed prior to the installation of counterpoise.

Data on the cases since 1934 in which flashover occurred on lines provided with preventive protection are given in table III.

It will be noticed that in six of the seven cases the indicated tower currents are greater than 50,000 amperes and in five of the cases they are of the order of 60,000 amperes. The latter group suggests that currents around 60,000 amperes are just above the maximum that can be carried without flashover by towers of the type used on the 66-kv lines. In 1937, a tower of the York line carried an indicated current of 63,200 amperes without flashover, which is the only case where a tower of the 66-kv lines carried current in excess of 50,000 amperes without flashover occurring. The tower footing resistance was seven ohms in this case, giving a calculated tower potential of 440 kv, 45 per cent of the normal safe maximum, or flashover level.

In the case of tower 99 of the Coatesville line in table III, it appears that the top conductor of circuit 13 was struck by lightning, causing the flashover. Tower 99 is a suspension tower.

These data on flashovers seem to show that there is a limiting current which towers can carry, irrespective of measured footing resistance. Due to recognized errors in the method of measurement of tower current, the results are not accurate, but a trend is indicated. For five out of six instances, flashovers occurred on 66-kv towers when tower currents were indicated in the order of 60,000 amperes. On the 132-kv line, the flashover recorded in table III was the only one which occurred in three cases where currents were in excess of 50,000 amperes. It is not clear whether the flashover was due to a combination of circumstances, the ground resistance of the counterpoise being relatively high within 300 feet of the tower (about $16^1/_2$ ohms) and a tall tower structure, or due to inadequate shielding. The available data seem to favor the first explanation.

The present-day theory[6] of the behavior of circuits carrying lightning surge currents indicates that there are two voltage effects present. One is the resistance drop which is at a maximum when the surge current is maximum, and the other is the reactance drop which is at its maximum when the current is changing most rapidly. These maxima obviously cannot occur at the same instant, but the maximum circuit voltage will occur somewhere in the interval between the instants of the maxima of the two component drop voltages. Either of the two may predominate, or their effects may be of equal importance, depending upon circuit conditions. From the flashover data presented here, it appears that when conditions are such as to give an indicated tower current of about 60,000 amperes, the rate of current change is sufficiently great to make the reactance component of drop appreciable. For towers, grounding, and insulation of the type used on the 66-kv lines considered, it apparently becomes predominant to the extent of almost always causing flashover. For towers, grounding, and insulation used on the 132-kv line, the reactive effect is appreciable, but apparently becomes of consequence only when tower heights and footing resistances are relatively great.

If future experience bears out the trend which now appears, there will be no advantage in reducing footing resistances below six or seven ohms for the type of 66-kv towers discussed here. Other types of construction will probably be found to have other values for the lowest worth-while limit of footing resistance.

VIII. Efficiency of Protection

The efficiency of a protective scheme can be computed by taking the ratio of the number of times strokes did not cause interruptions to the number of strokes. The efficiencies of the lightning protection during the years that the lightning current study has been in progress on the several lines are given in table IV. The true efficiencies may be slightly higher than those given in table IV because of

Table I. Deviation From Equal Division of Lightning Current in Tower Legs

Tower Current Range (Amperes)	Towers With Links of One Polarity		Towers With Links of Both Polarities		All Towers in Range	
	Cases	Average Deviation (Per Cent)	Cases	Average Deviation (Per Cent)	Cases	Average Deviation (Per Cent)
1– 5,000	61	73	35	90	96	80
5,001–10,000	45	27	7	83	52	35
10,001–15,000	26	23	2	119	28	29
15,001–20,000	9	32	0		9	32
20,001–25,000	7	32	0		7	32
25,001–30,000	8	17	0		8	17
30,001–35,000	2	5	0		2	5
35,001–40,000	1	10	1	89	2	50
40,001–45,000	2	15	0		2	15
45,001–50,000	1	14	0		1	14
50,001–55,000	0		0		0	
55,001–60,000	1	6	0		1	6
60,001–65,000	1	6	0		1	6
Totals	164		45		209	

possible multiple records or weak records on the surge-crest ammeter links.

It is of some interest to note the extremely high efficiency of protection which is required to limit to a low figure the number of tripouts over a period of years.

IX. Efficiency of Shielding

The relative merits of one and two overhead ground wires and of the many possible positions in which they may be placed have been studied by many investigators at great length theoretically, and in the laboratory.[6] From the lightning current data which have been collected, it is possible to evaluate the efficiency under operating conditions of the various arrangements used on the lines to which reference is made here.

For an overhead ground wire to shield a line conductor from direct strokes, the line conductor must lie within the protective zone of the ground wire. In figures 2, 3, 4, and 5 are indicated the minimum protective shielding zones that the respective overhead ground wires must provide. Where a single overhead ground wire has been installed, the required protective zone is wider for a strain tower than for a suspension tower, as shown in figure 2. This is because the conductor is at the height of the cross arm on a strain tower, and below the cross arm on a suspension tower by the length of an insulator string. Where two overhead ground wires have been installed on the newer lines of the company, the overhead ground wires have been elevated at strain towers to maintain the same clearances above line conductors as is provided at suspension towers. The protective zones required on strain and suspension towers having such construction are, therefore, the same. (See figures 3, 4, and 5.)

From the number of flashovers and recorded strokes to the several classes of transmission lines, the minimum efficiencies of the shielding arrangements can be computed. The number of flashovers which have occurred are known accurately for practical purposes from the tripouts which have occurred. The recorded strokes to a line may be slightly less than the actual number due to more than one stroke affecting a set of links between inspections and calibrations. Ignoring some strokes because of the weak magnetic effect produced will also affect the number of reported strokes in the same manner.

When a flashover occurs, there may be some question of the cause being inadequate shielding or high-tower potential. If some flashovers are believed to be caused by excessive footing resistance or tower current, there will be less chargeable to imperfect shielding.

$$\text{Efficiency of shielding} = 100\left(1-\frac{\text{outages}}{\text{strokes}}\right)\text{per cent}$$

The maximum probable efficiency is obtained when the number of outages believed due to poor shielding is used in the expression, and the minimum efficiency when the total number of outages is used. The latter figure is, of course, the pessimistic one.

It can be seen in figures 3 and 4 that the shielding conditions on the 220-kv and 132-kv lines are practically identical. In table V the data for these two classes of towers are combined.

The behavior of the lines with two overhead ground wires is in agreement with the behavior predicted from surge tests on miniature models, but that of the line with one overhead ground wire is much better. In the latter case the shielding on the suspension towers is theoretically superior to that on the strain towers, but their behavior during the period of study has been practically the same.

X. Comparison of Calculated Probable Outages and Actual Outages

Some years ago Lewis and Foust[7] suggested that, as a result of their studies,

Table II. Strokes to Lines

Line	Length in Miles	Year	Recorded Strokes In Year	Recorded Strokes Average	Strokes Per 100 Miles In Year	Strokes Per 100 Miles Average
Safe Harbor-Westport-Takoma 230 kv	91.8	1935	115		125	
		1936	108		118	
		1937	87		95	
		1938	54		59	
		1939	118		129	
				96		105
Safe Harbor-Riverside 220 kv	50.5	1938	46		91	
		1939	45		89	
				46		90
Safe Harbor-Perryville 132 kv	31.5	1935	27		86	
	31.5	1936	69		219	
	31.5	1937	44		140	
	33.8	1938	56		166	
	33.8	1939	53		157	
				50		154
Holtwood-York 66 kv	22.8	1936	31		136	
		1937	41		180	
		1938	15		66	
		1939	22		97	
				27		120
Holtwood - Coatesville 66 kv	29.4	1936	30		102	
		1937	25		85	
		1938	68		232	
		1939	45		153	
				42		143
Holtwood - Baltimore 66 kv (2 lines) and Philadelphia Road-Gunpowder 110 kv	40 (of right-of-way)	1939	66		165	
				66		165

Average strokes per 100 miles of line per year for all lines except the last in the list is 126.

flashovers of shielded transmission lines only occur when tower potentials exceed the insulation strength of the given line. The tower potential in each case was taken as the product of tower footing resistance and tower lightning current. Based on this theory a method was suggested several years ago by the present writer for calculating the probable outages of shielded transmission lines.[6] In table VI a comparison is made between the actual flashovers experienced on the several lines and the calculated behavior.

For all but one of the lines, the actual performance has not been as good as the estimated. The record of flashovers given in table III shows that flashovers can be caused by tower currents less than those predicted from the theory based on tower footing resistance drop.

As the original empirical Lewis and Foust rule,[7] the data used in the probability calculations, and the records found when flashovers occurred are all based on the same measurement method, any discrepancies between calculated and actual outages do not seem to be attributable to neglecting the current carried by tower cross braces. The discrepancies are, therefore, thought to result from the impedance drop in the tower structure and footings being appreciable.

To make the probability calculations conform to field experience, the theory must be modified to state that flashover does not occur unless the product of tower current and tower footing resistance exceed the insulation level of the line, or unless the tower current exceeds the characteristic safe current for the given tower and grounding arrangement. The characteristic safe current seems to be around 60,000 amperes for the 66-kv lines. From the circumstances attending the single flashover which occurred on the 132-kv line, from the relative insulation strengths of the 66- and 132-kv lines, and from other data, it is estimated that the characteristic safe current of this 132-kv line is probably around 90,000 to 100,000 amperes. Experience with the 220-kv lines seems to indicate that the safe characteristic current of the towers, grounding, and insulation used on these lines probably is in excess of those occurring in nature. The only flashover experienced on the 220-kv lines occurred in 1933 at a tower having a footing resistance of 25 ohms. This was before the lightning current studies were begun, but the flashover can be accounted for on the basis of the original Lewis and Foust theory by assuming a tower current of 100,000 amperes, a value which has been measured several times in the field.

Table III. Flashovers on Transmission Lines Provided With Preventive Lightning Protection

Line and Tower	Year	Tower Current in Amperes	Tower Footing Resistance in Ohms	Tower Height in Feet	Tower Potential (I×R) (Kv)	Ratio of Tower Potential to Flashover Level
Holtwood-York 63 (66 kv)	1937	58,400	13.8	75	805	0.82
Holtwood-York 145 (66 kv)	1937	60,000	19	76	1140	1.16
Holtwood-Coatesville 40 (66 kv)	1938	64,400	17.2	73	1108	1.30
Holtwood-Coatesville 97 (66 kv)	1939	60,200	5.4	83	325	0.38
Holtwood-Coatesville 99 (66 kv)	1939	13,400	8.5	73	115	0.14
Holtwood-Baltimore 130–56 (66 kv)	1939	62,800	3.6	67	225	0.26
Safe Harbor-Perryville 15 (132 kv)	1939	52,600	12.2	137	640	0.41

Table IV. Efficiencies of Preventive Lightning Protection

Line	Years of Study	Lightning Outages*	Recorded Strokes	Efficiency of Protection (Per Cent)
Safe Harbor-Westport-Takoma 220 kv	5	0**	482	100**
Safe Harbor-Riverside 220 kv	2	0	91	100
Safe Harbor-Perryville 132 kv	5	1	240	99.6
Holtwood-York 66 kv	4	2	109	98.2
Holtwood-Coatesville 66 kv				
Before improvements	2†	37	55	33
After improvements	2	3	113	97.4
Holtwood-Baltimore 66 kv (Two lines on one right-of-way)	1	1‡	65	98.4

*Single, double, and triple circuit tripouts.

**A flashover of this line occurred in 1933 before the lightning current studies were begun. The estimated efficiency for the entire eight years of operation is:

$$100\left(1-\frac{1}{8/5\times 482}\right)=99.9 \text{ per cent}$$

†Stroke records are complete for only two years (1936 and 1937).

‡Not included is one tripout which occurred before the installation of counterpoise was completed in 1939.

The probable outages for the lines have been recalculated in table VII using the estimated safe characteristic tower currents given above as the maxima that can be carried under any circumstances. The calculations may possibly be further refined in the future when tower and footing impedances become evaluated and their effect in combination with footing resistance is determined quantitatively.

XI. Lightning Arrester Records

Surge-crest ammeter links have been mounted on the lightning arresters at Highlandtown substation in Baltimore since 1935. These arresters are connected to the four 25-cycle, 66-kv circuits of the two Holtwood-Baltimore lines. Each year since their installation, except 1936, they have indicated some current in at least three of the four arrester banks. The maximum current recorded was 2,600 amperes in 1937.

Similarly, arresters connected to other 66-kv circuits have carried small currents from time to time. The largest current recorded was 7,400 amperes in 1939 in the arresters connected to circuit 83 at Violet Hill substation in York. Circuit 83 is an unshielded wood-pole line of the Metropolitan Edison Company connecting through the high-tension bus at the substation to the Holtwood-York 66-kv line.

It is interesting and of some importance to note that during three seasons of study, no indications have been obtained of discharges through any of the four banks of arresters connected to circuits protected by two overhead ground wires and buried counterpoise systems.

XII. Summary

1. Because of the large number of observations, 3,289, which have been made during the six years of study of lightning currents, some confidence can be felt that the data are fairly representative of the several effects of lightning. Some uncertainties still exist in the data, as for instance the effect of tower cross braces on the measurement of tower currents.

2. The distribution curve of the various magnitudes of currents in towers believed

Table V. Efficiencies of Shielding

Type of Line	Years of Record	Number of Strokes	Number of Outages	Estimated Strokes to Conductors	Probable Efficiencies of Shielding	
					Minimum (Per Cent)	Maximum (Per Cent)
220 kv (2 lines) (figure 3)	7*	573	0*	0		
132 kv (figure 4)	5	249	1	0		
	12	822	1	0	99.9	100
66 kv (figure 2)						
(1 overhead ground wire)						
Strain towers	2	30	1	0	97	100
Suspension towers	2	83	2	1	98	99
66 kv (figure 5)						
(2 overhead ground wires)	4	109	2	0	98	100

*Includes only years of lightning current study. See table IV.

to have been struck by lightning has been established from 1,201 records. The curve can be used satisfactorily for purposes where the error due to cross braces is not objectionable. Considerable confidence can be placed in the general shape of the curve.

3. Over a period of years it appears that all sections of the transmission lines of the Pennsylvania Water and Power Company are struck by lightning, there being no localities that are immune.

4. The average number of strokes to the transmission lines studied is 126 per 100 miles per year. The actual number of strokes to a given transmission line, however, may vary in the ratio of as much as three to one from year to year. This variation emphasizes the need for examining lightning experience records for a period of several years before any conclusions are reached about lightning phenomena.

5. Analysis of the flashovers which have occurred on lines having overhead ground wires and buried counterpoise systems indicates that flashovers can be caused not only by the ground resistance drop being greater than the insulation strength, but also by the reactive drop due to the rapid rates of current rise which seem to accompany heavy tower currents. On the observed 66-kv lines this latter phenomenon seems to be of critical magnitude when the indicated tower currents have been around 60,000 amperes.

6. Because of this latter phenomenon it appears that no advantage accrues from reducing tower footing resistances on such lines below approximately six ohms. This figure allows for suspected inaccuracies in the measurement of tower lightning currents and footing resistances. It is thought to be desirable that this value of footing resistance be obtained within not more than 200 or 300 feet of the tower base.

7. Operating experience shows that the arrangement of the two overhead ground wires on the newer lines of the company provides practically perfect shielding, that is, probably within less than 0.1 per cent. The experience with a single overhead ground wire is superior to that predicted from laboratory models. The record shows the shielding to be effective for about 98 or 99 per cent of the strokes contacting the Holtwood-Coatesville 66-kv line.

8. Preventive protection embodying the use of overhead ground wires and buried counterpoise installations co-ordinated with line insulation has been shown to be very effective. Since this work has been carried out completely on the 220-kv lines it has been 100 per cent effective. It has been 99.6 per cent effective on the 132-kv line and about 98 per cent effective on the 66-kv lines.

9. Discrepancies were found in the comparison of actual and calculated probable lightning outages. These have been traced to the phenomenon of a maximum surge current which a given construction can apparently withstand irrespective of the measured tower footing resistance.

10. The lightning arresters connected to transmission lines provided with effective preventive protection are seldom called upon to carry lightning discharges, and then they are apparently of small magnitudes.

Table VI. Comparison of Actual and Probable Outages

Probable Outages Calculated on Basis of Lewis and Foust Theory as Originally Presented†

Line	Years of Record	Lightning Outages Per Year	
		Actual	Probable
Safe Harbor-Westport-Takoma 220 kv	8	0.13	0.014
Safe Harbor-Riverside 220 kv	2	0	0*
Safe Harbor-Perryville 132 kv	5	0.2	0.0078
Holtwood-York 66 kv	4	0.5	0.29
Holtwood - Coatesville 66 kv	2	1.5	0.68
Holtwood - Baltimore 66 kv (Two lines on one right-of-way)	1	1	0.2

* Does not include section 1.03 miles in length where there are no overhead ground wires.

Table VII. Comparison of Probable and Actual Outages

Probable Outages Calculated on Basis of the Suggested Modification of the Lewis and Foust Theory

Line	Estimated Safe Maximum Current	Lightning Outages Per Year	
		Actual	Probable
Safe Harbor-Westport-Takoma 220 kv	Greater than 150,000 A	0.13	0.014
Safe Harbor-Riverside 220 kv	Greater than 150,000 A	0	0*
Safe Harbor-Perryville 132 kv	90,000 A	0.2	0.05
Holtwood-York 66 kv	60,000 A	0.5	0.58
Holtwood-Coatesville 66 kv	60,000 A	1.5	1.3**
Holtwood-Baltimore 66 kv (Two lines on one right-of-way)	60,000 A	1	1

*Does not include 1.03 miles section where there are no overhead ground wires.

**Includes allowance for shielding being only 99 per cent efficient. (See section IX.)

References

1. Safe Harbor-Westport 230 Kv Transmission Line, **Edwin Hansson.** Electrical Engineering, volume 51, December 1932, pages 834–8.

2. Direct Measurement of Surge Currents, **C. M. Foust and J. T. Henderson.** AIEE Transactions, volume 54, 1935 (April section), pages 373–8.

3. Lightning Investigation on a 220-Kv System—III, **Edgar Bell.** AIEE Transactions, volume 59, 1940, pages 822–8.

4. Lightning Investigation on Transmission Lines—VII, **W. W. Lewis and C. M. Foust.** AIEE Transactions, volume 59, 1940 (April section), pages 227–32.

5. Theory and Tests of the Counterpoise, **L. V. Bewley.** AIEE Transactions, volume 53, 1934 (August section), pages 1163–72.

6. Shielding of Transmission Lines, **C. F. Wagner, G. D. McCann, and G. L. MacLane, Jr.** AIEE Transactions, volume 60, 1941.

7. Lightning Investigation on Transmission Lines—IV, **W. W. Lewis and C. M. Foust.** Electrical Engineering, volume 53, 1934 (August section), pages 1180–6.

8. Probable Outages of Shielded Transmission Lines, **S. K. Waldorf.** AIEE Transactions, volume 56, 1937 (May section), pages 597–600.

High-Voltage Bushings Designed to Meet Modern Service

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Introduction

BUSHINGS are a very important part of over-all system insulation. Since all of the power transmitted from station to station and station to consumer passes through a great many bushings the majority of which are a part of vital equipment such as transformers, breakers, etc., it is immediately apparent that system-service continuity depends, to a large degree, upon satisfactory bushing operation. Early bushing designers were handicapped by a lack of operating history and high-voltage testing facilities. However, in spite of these handicaps they developed some sound designs as evidenced by the many 25- to 30-year-old bushings in satisfactory service today. In these early bushings porcelain was one of the principal dielectrics.

Comprehensive studies of porcelain oil-filled bushings have been made to improve both the electrical and mechanical characteristics. As a result of these studies a better understanding of the internal and external electrostatic field conditions has resulted, and a new method of voltage grading developed. Mechanical improvements have been made which not only simplify construction, but stabilize the electrical characteristics by maintaining the over-all assembly close to its original condition. These developments will be discussed here.

Control of Electrical Characteristics in Bushing Design

Design Requirements

From an electrical standpoint, a bushing must have adequate internal insulation to provide a safe margin between internal puncture and external flashover. There also should be no corona formation at operating voltage and radio interference must be kept at a minimum. The over-all electrical characteristics of a bushing should be stabilized in so far as they affect operating performance. A design which has excellent electrical characteristics in the laboratory, but is subject to change under operating conditions, is undesirable if these changes adversely affect the performance. Extensive tests have been made in the laboratory and operating records have been carefully checked to guard against this possibility.

A bushing must provide sufficient insulation in two ways. First, it must have the required external flashover voltage commensurate with its rating and the insulation level of associated equipment, and secondly, the internal puncture strength must have a satisfactory margin over the external flashover. Since external flashover of a bushing is through a surrounding medium, such as the air around the upper or weather end, full consideration must be given the characteristics of this medium to obtain the balanced design necessary for stable electrical performance.

Porcelain oil-filled bushings use insulating materials of differing dielectric constants or flux-carrying capacities. With insulation in series there is a tendency for those of lower dielectric constants to have imposed relatively greater portions of the total voltage. Accordingly, it is essential that high localized stress be avoided in those insulating zones having low dielectric constants. This applies to the medium surrounding the bushing, as well as the insulation within it.

Means of Controlling Characteristics

In order to determine the effectiveness of voltage grading or electrostatic field-controlling arrangements a series of impulse and 60-cycle studies were made. Many assemblies were tested, but only representative types having practically the same striking distance will be discussed here. These are shown in figure 1.

In figure 2 are shown photographs of corona due to 60-cycle overstress on the assemblies of figure 1. Figure 3 shows photographs of the field patterns around these same assemblies as indicated by corona from impulse-suppressed discharges. Complete electrical data on the above assemblies, along with voltages applied in the various photographs, are given in table I.

In figure 1*a* is shown a porcelain tube with a metal cap and flange, but *without* a central conductor. Appreciable 60-cycle corona can be seen at the cap in figure 2*a*, while a uniform field pattern exists in figure 3*a* for both polarities. This assembly is included to show the radical change in the field when a conductor is passed through the center of the tube. Figure 1*b* is the same as figure 1*a* except *with* a central conductor added. Heavy 60-cycle overstress is apparent in figure 2*b* immediately above the metal flange and figure 3*b* shows the field overstress due to suppressed discharges.

The difference between the positive and negative field patterns of figure 3 is in accord with observations made on the study of dielectric fields existing between various types of electrodes in air.[1] It is possible to control these stresses to some degree by the shape and arrangement of electrodes and by various methods of grading. The central conductor of figure 1*b* has changed the electrostatic field so that the air at the edge of the flange is highly overstressed. This overstress is due to the low dielectric constant or flux-carrying capacity of air as compared to porcelain. The air space between the central conductor and the porcelain is subject to overstress for the same reason. These two regions are the cause of unstable flashover and radio-interference characteristics in this type of bushing.

In contrast with figure 2*a* there is no overstress at the cap in figure 2*b*. The central conductor shields the cap since most of the electrostatic flux lines emanating from the flange terminate on the central conductor well below the cap. Figure 4 shows the approximate field condition for figure 1*b*. Initial overstress starts in the air immediately above the flange at *A*. As the voltage is increased, the air becomes ionized, forming a conducting envelope over the porcelain surface to a point where flashover occurs at a rather low voltage.

In figure 1*c* is illustrated a typical solid porcelain bushing. Figures 2*c* and 3*c* show its 60-cycle and impulse corona patterns, which are similar to those of figures 2*b* and 3*b*. The performance of the figure 1*c* design can be improved somewhat by changing the porcelain configuration.

Oil-filled bushing designs readily adapt themselves to the elimination of localized overstress. For example figure 1*d* is a

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1. For numbered reference, see end of paper.

Figure 1. Details of bushing construction

Figure 2. Corona due to 60-cycle overstress

Figure 3. Corona due to suppressed impulse discharge

Positive Polarity

Negative Polarity

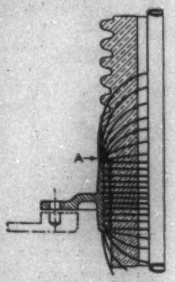

Figure 4. Field pattern for figure 1b

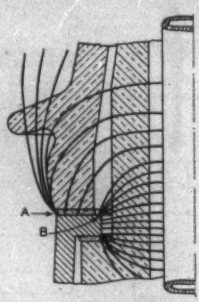

Figure 5. Field pattern for figure 1d

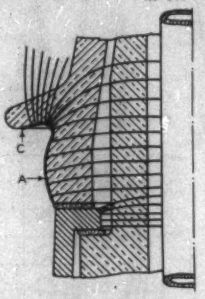

Figure 6. Field pattern for figure 1d near flashover

simple oil-filled assembly with no grading means other than its porcelain configuration. The 60-cycle corona in figure 2*d* shows the heavy overstress immediately above the flange. The approximate field condition around the flange area of the figure 1*d* design below the point of excessive corona is shown by figure 5. The inside air between the conductor and the porcelain has been replaced by a combination of oil and wrapped insulation, thereby preventing overstress in this area. However, no effort has been made to control the field at the mounting flange, thereby resulting in two highly stressed regions. One is at *B*, figure 5, inside the bushing where the flange terminates in the oil; the other is at *A*, the outer exposed edge of the flange. The voltage gradient at *B* is higher than at *A*. However, since the dielectric strength of the oil at *B* is appreciably higher than that of the air at *A*, overstress appears first at *A* at a lower voltage gradient.

This overstressing at *A* establishes a conducting envelope of ionized air with increasing voltage. It does not progress up the bushing as far as on figure 2*b* but stops under the first petticoat. This is due to the conducting envelope assuming a form of grading means, as shown by figure 6. This same condition is shown in figure 2*c* where overstress stopped abruptly under the porcelain petticoat. This has not been generally appreciated and many bushings have been made in both the solid and oil-filled types with the region from *A* to *C*, figure 6, unstable, thereby involving possible radio interference.

Figure 1*e* is similar to figure 1*d* except that a capacity grading means in the form of an insulation-wrapped metal core is incorporated. The metal core and the metalizing on the porcelain tube are electrically connected to the flange. Since the wrapped metal core extends up inside the bushing, it partially shields the outside exposed edge of the mounting flange. At the same time it reduces the voltage stress in the oil at the inside edge of the flange and at the top edge of the metalizing on the porcelain tube. Covering the metal with insulation is essential for proper field control. Tests on various forms of uninsulated metal grading means have proved them to be relatively ineffective.

The approximate field condition of figure 1*e* is shown by figure 7. The metalized, ground potential surface on the porcelain shorts out the highly stressed oil at *B* in figure 5. The point *A* is not completely shielded since it goes into corona as shown by figure 2*e*. However, the corona is materially reduced from that shown on figure 2*d*. In table I, figures 1*d* and 1*e* are seen to have practically the same 60-cycle flashover although an appreciable difference exists in the radio-interference values. This is because at flashover voltage the external field control set up by the conducting envelope of corona in figure 2*d* and the grading means of figure 2*e* are equally effective in so far as flashover voltage is concerned.

In the lower operating voltage bushings, namely 69 kv and below, cover opening diameters have been somewhat restricted. The problem here has been to develop the most efficient methods of using the available space. Various voltage grading arrangements have been used, but most of them require space which can be used better for effective insulation between the central conductor and ground. A newly developed method, not requiring this, is a form of resistance grading by means of conduction glaze applied directly to the porcelain surface. Figure 8 shows the approximate field of the figure 1*f* design which utilizes this resistance grading.

Figure 7, the type used in figure 1*e*, can be called an auxiliary means since it is not integral with the porcelain. Figure 9 is an effective field-controlling arrangement used on present high-voltage bushing designs of ratings, 92 kv and above. This type, formed integral with the porcelain, is very effective where space permits its use. The types in figures 7 and 9 function by means of their configuration and the voltage drop through a dielectric. Figure 8 functions because of the voltage drop through a high resistance. There must be enough voltage drop along the conduction-glazed surface from *D* to *E* to prevent overstressing at both *D*, the

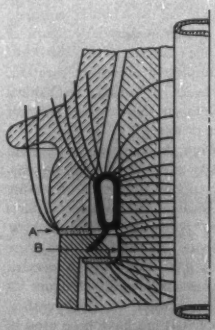

Figure 7. Field pattern for figure 1e

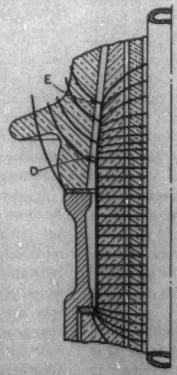

Figure 8. Field pattern for figure 1f

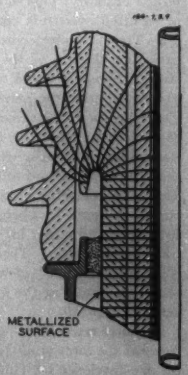

Figure 9. Field pattern for figure 11

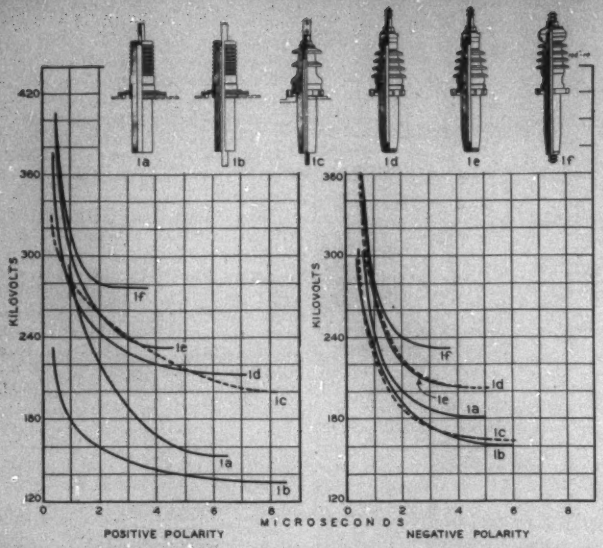

Figure 10. Volt-time characteristics of assemblies in figure 1

end of the metalizing, and at *E*. This means that the resistance of the conduction glaze region from *D* to *E* must be maintained within definite limits by careful manufacturing control. Likewise, the conduction glaze must have permanently stable characteristics.

Figure 1*f* illustrates a modern bushing using resistance grading. Figure 2*f* shows a very light glow between the petticoats with 120 kv, 60 cycle applied on the bushing. This shows the absence of localized overstress outside the bushing. The radio interference (table I) indicates the absence of the internal overstress. Figure 8 shows the field condition discussed in the previous paragraph. This construction improves the electrical characteristics materially by approaching the uniform field of a sphere gap rather than the concentrated field of a rod gap. This is particularly emphasized by the curves in figure 10 where this design is seen to have a rather high and flat volt-time characteristic. The other extreme is the design of figure 2*b* whose poor field condition results in the lowest volt-time curve of figure 10.

Bushings rated 92 kv and above have received the same study, and figure 11 is the one developed for 115-kv service. It is provided with capacitance grading of the type shown in figure 9, and gives proportionately the same performance as figure 1*f*. Since these modern designs are stable at voltages considerably in excess of their rating, it is safe to assume that their characteristics will remain unchanged under normal operating conditions.

Mechanical Improvements

Excellent electrical properties are of little value if the mechanical design does not maintain the bushing at or near its original condition for a long period of time. This requires, primarily, sturdy construction with efficient gasket joints and one that will maintain a stable condition of the oil. Figure 11 shows a modern bushing having these characteristics.

An early design is shown by figure 12 where all of the external parts of the bushing were completely cemented together. If gasket leaks or other mechanical troubles developed, there arose a difficult maintenance problem.

A later design, shown in figure 13, could be more easily maintained since the gasket joints could be tightened or readily replaced. However, the large metal parts cemented to porcelain presented occasional problems. In the first place there was the possible chance of a cement change with time where joint *A*, figure 13, was directly exposed to the weather. Weatherproof coatings have been used to prevent cement deterioration, but under extreme conditions they have been found

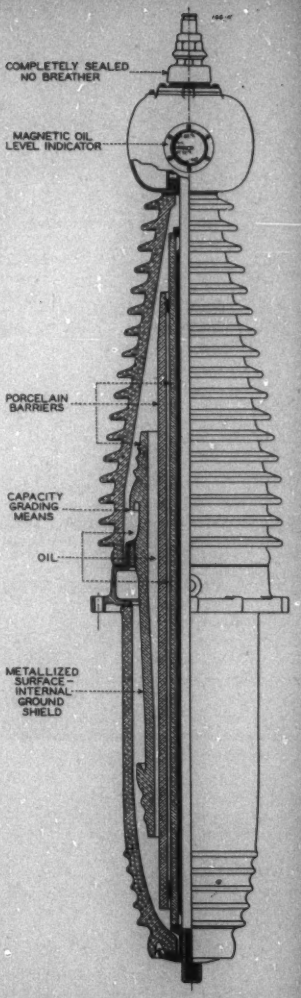

Figure 11. Present design, high-voltage porcelain oil-filled bushing

wanting. Also a differential thermal expansion existed between the metals and porcelain. Special treatment of the cement joints to compensate for thermal expansion has also been tried. There are many thousands of large oil-filled bushings such as those of figures 12 and 13 in service which have given a good account of themselves, but gasket leaks and damaged porcelain are not uncommon.

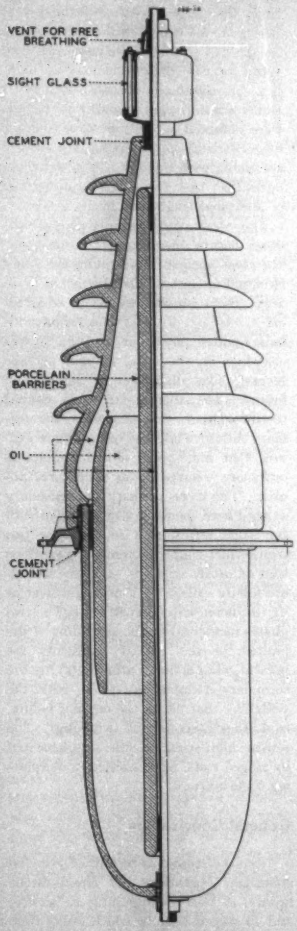

Figure 12. High-voltage porcelain oil-filled bushing of early design (1920)

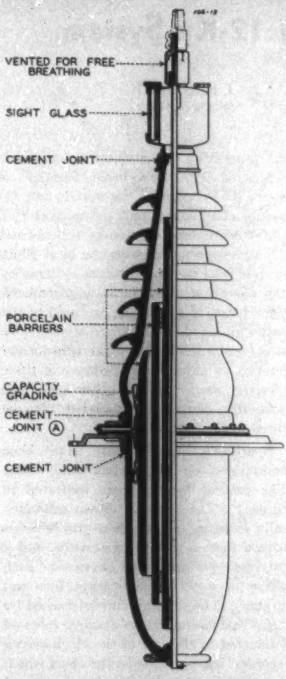

Figure 13. High-voltage porcelain oil-filled bushing of ten years ago

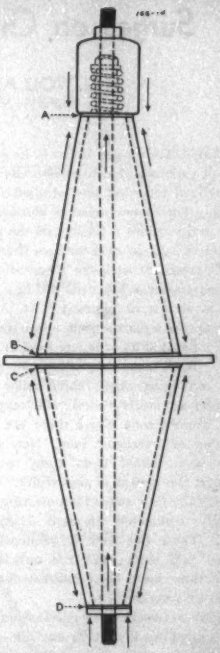

Figure 14. Schematic view of compression assembly showing how gaskets are kept under compression

Several years ago the full compression-assembled bushing was introduced. This produced a very rugged assembly, eliminated external cement joints, and kept the gasket joints permanently oil-tight. It is a well-established fact that most gasket materials kept under constant pressure between mating surfaces remain oil-tight indefinitely. Formerly, gaskets had to keep themselves tight. To illustrate this, when the gaskets in bushings such as figure 13 were originally tightened, the material, due to its initial resilience, exerted a strong back pressure against the mating surfaces. However, this back pressure for practically all gasket materials diminishes with time. In addition some shrink or take a permanent set. In any event, in a relatively short time the gasket joint is not as effective as when first made.

The full-compression assembly shown

Table I

Assembly Figure Number	Corona Due to 60-Cycle Overstress: Kv (RMS) on Assembly	Corona Due to 60-Cycle Overstress: Photo Figure Number	Corona Due to Impulse Suppressed Discharge: Kv (Crest) on Assembly*	Corona Due to Impulse Suppressed Discharge: Photo Figure Number	60-Cycle Flashover (Kv RMS): Dry	60-Cycle Flashover (Kv RMS): Wet	Critical Flashover 1½ x 40-Microsecond Wave Kv (Crest): Pos.	Critical Flashover 1½ x 40-Microsecond Wave Kv (Crest): Neg.	Radio Interference Voltage on Bushing for 100-Microvolt Level Kv (60 Cycle RMS)
1a	89	2a	377	3a	91	72	153	182	41.2
1b	75	2b	305	3b	77	65	133	161	20.1
1c	81	2c	315	3c	95	74	202	165	21.2
1d	81	2d	350	3d	115	78	211	204	21.2
1e	81	2e	350	3e	119	88	234	206	44.7
1f	118	2f	422	3f	131	93	276	233	118.0

*Wave is "chopped" by parallel rod gap, allowing voltage considerably above critical flashover value.

Surges on Chicago 12-Kv System

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VOLTAGE surges on the 12-kv system of Commonwealth Edison Company have been recorded and studied for 20 years. This paper presents the Chicago data and outlines a theory for the explanation of system overvoltages that is in good agreement with the observations.

A geographical layout of the 12-kv system is shown in figure 1. At present there are six separate zones consisting of a station bus and its associated radial 12-kv lines. Each zone has about 50 or 60 lines averaging about three miles long. All lines are underground cable except in the Calumet zone where there are some sections of overhead line. New zones have been added from time to time through the period of this study. Prior to 1928 the four zones then existing were directly connected through 12-kv tie lines. These ties were subsequently removed and since 1928 the only interconnections have been indirect through the 66-kv system.

Figure 2 is a schematic one-line diagram of a typical bus layout for any one of the six generating or distributing stations in Chicago. The two basic features of every 12-kv zone in the system are (1) independent feed of bulk power from each of the two independent 66-kv systems and (2) provision for splitting the local 12-kv system into two independent systems by the operation of sectionalizing breakers. Two types of grounding are used in the zones involved in the surge studies. In one type a derived neutral transformer having an inductive impedance of three ohms is used. In the other type, one generator neutral is grounded through three ohms of resistance.

Spark-gap installations have been maintained on the system since 1919. The present locations are indicated in figure 1. The device is shown schematically in figure 3. A sphere gap in series with a fuse, a protecting resistor, and a recorder is connected between each phase of a 12-kv substation bus and ground. The surge of current caused by a gap flashover operates a simple solenoid connected to the pen of the clock-driven recorder, leaving a jog on the chart which shows when the overvoltage occurred and which phase it was on. The magnitude of the overvoltage remains unknown, except that the breakdown of the gap establishes its lower limit. The gap settings have been adjusted from time to time through the 20 years of the study to cover the range 1.85 times normal crest voltage to 3.5 times normal crest voltage. As the gap settings were increased there was a corresponding decrease in the number of overvoltages recorded, until at 3.5 times normal crest voltage no records were obtained. The time of occurrence of each spark-gap operation is carefully correlated with the daily log of switching operations and the oscillograph records of abnormal conditions in the system.

The oscillograph records provide another distinct line of attack on overvoltage phenomena by facilitating the study of simultaneous or "sympathetic" failures. Such occurrences consist of a failure in one part of the system, followed almost immediately by one or more failures elsewhere in the same system, perhaps several miles distant from the original failure. The original failure is referred to throughout this paper as the primary failure while the one or more failures that may occur almost simultaneously are referred to as secondary failures. The terms primary and secondary as used here should not be confused with the same terms used to designate two transformer-coupled circuits. Questions that naturally arise are: (*a*) Is the secondary failure caused by a brief transient or by the increase in 60-cycle voltage on two phases incidental to the grounding of the faulted phase? (*b*) If transients are present, what is their nature? (*c*) Are the secondary failures associated with the switching that clears the original failure, or do they precede such switching? The routine high-speed records, supplemented by staged tests, have assisted in elucidating these matters.

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General Conclusions

From the studies of records of over 700 spark-gap operations, 54 simultaneous failures of lines or apparatus in service, and 15 staged tests in which faults were thrown on the system, the following conclusions have been drawn:

1. The maximum magnitude of overvoltages on this system is about 3.5 times normal crest voltage.

2. The overvoltages of highest magnitude are associated with system failures and are best understood by use of the "cancellation-wave" theory; the highest transients occur at the inception of the fault, not during the switching that clears the fault.

3. Overvoltages associated with routine switching are amenable to the "cancellation-wave" theory, but are usually of smaller magnitude than those associated with failures and are therefore of less interest.

4. Most secondary failures in simultaneous failures are caused by the overvoltages mentioned in conclusion 2.

in figure 11 compensates for all gasket variations since the mating parts are continually acted upon by the compression spring in the oil reservoir. This is shown schematically in figure 14 which indicates how the compression loading of the spring is transmitted to the various gasket surfaces at *A*, *B*, *C*, and *D*. The compression spring must have adequate "pickup" or deflection so that any shrinkage of the gaskets will not release the spring enough to affect its loading appreciably.

With dependable gasket joints now available, it is possible to have a completely sealed bushing. This has been done over an entire range of oil-filled porcelain bushings to secure a stable oil condition. Moisture, oxygen, and sunlight are all detrimental to insulating oil, but by completely isolating the oil from them, its dielectric properties remain practically constant. Where it is desired to check the oil level occasionally, especially in the larger bushings, a magnetic oil level indicator is used. This affords a definite indicating means without exposing the bushing oil to sunlight, moisture laden air, etc.

In order to keep the pressure in the bushing within reasonable limits, adequate space in the top oil reservoir shown must be provided for oil expansion due to temperature changes. The compression spring arrangement must be adequate to keep the gasket joints tight against the various pressures in the bushing.

Reference

1. THE CONTROL GAP FOR LIGHTNING PROTECTION, Ralph Higgins and H. L. Rorden. AIEE TRANSACTIONS, volume 55, 1936 (September section), pages 1029–34.

5. The overvoltages on the Chicago 12-kv system are essentially power-frequency phenomena.

6. When an overvoltage condition is set up, it is propagated throughout all parts of the system that have direct metallic connections, but is strictly confined to such metallically connected parts.

7. Secondary failures occur only in insulation that is deteriorated to the point where it will not withstand (*a*) 60-cycle overvoltage of value 1.73 times normal crest to ground applied for the duration of a system fault to ground, (*b*) a few cycles of transient overvoltage having a maximum magnitude of 3.5 times normal crest to ground.

8. Zones having a derived neutral ground, which is essentially inductive, have more and higher transient overvoltages than zones having the generator neutral grounded through resistance.

9. The number and magnitude of overvoltages recorded in the zone having some sections of 12-kv overhead line, excluding overvoltages due to lightning and unknown causes, were about the same as for the zones in which all the lines were underground.

Spark-Gap Data

The data on system overvoltages obtained in the period 1919–28, when all the 12-kv zones were directly interconnected, are shown in figure 4. A few surges exceeded 3.2 times normal, which was the highest gap setting used in this period. The recording devices were needle gaps. Similar data for sphere gaps (one-inch spheres) are given in figure 5 for the period 1932–38, when the zones were not directly interconnected. A few overvoltages exceeded three times normal, but none exceeded 3.5 times normal. The latter setting was maintained at all spark-gap installations for about $1\frac{1}{2}$ years. From this it appears that the maximum overvoltages on the system do not exceed 3.5 times normal. The needle-gap and sphere-gap data both show that overvoltages associated with failures are usually higher than overvoltages associated with routine switching.

The correlation of overvoltages with failures is shown in figure 6. About 40 per cent of all faults are accompanied by overvoltages of twice normal or greater. Only about six per cent of the faults are accompanied by overvoltages exceeding three times normal.

Comparing figures 4 and 5, it is seen that more overvoltages of a given magnitude occurred during 1919–28, when needle gaps were used, than during 1932–38, when sphere gaps were used. The reasons are threefold:

(*a*). The zones were directly interconnected in 1919–28, so that a system disturbance might leave a record at every spark-gap installation, instead of at only one or two as was the case for 1932–38.

(*b*). There were many more failures, hence many more chances of having system overvoltages, in the 1919–28 period than in 1932–38.

(*c*). Needle-gaps have a greater tendency than sphere gaps to flash over at less than the nominal setting as a result of ionization and accumulation of dust in the gap.

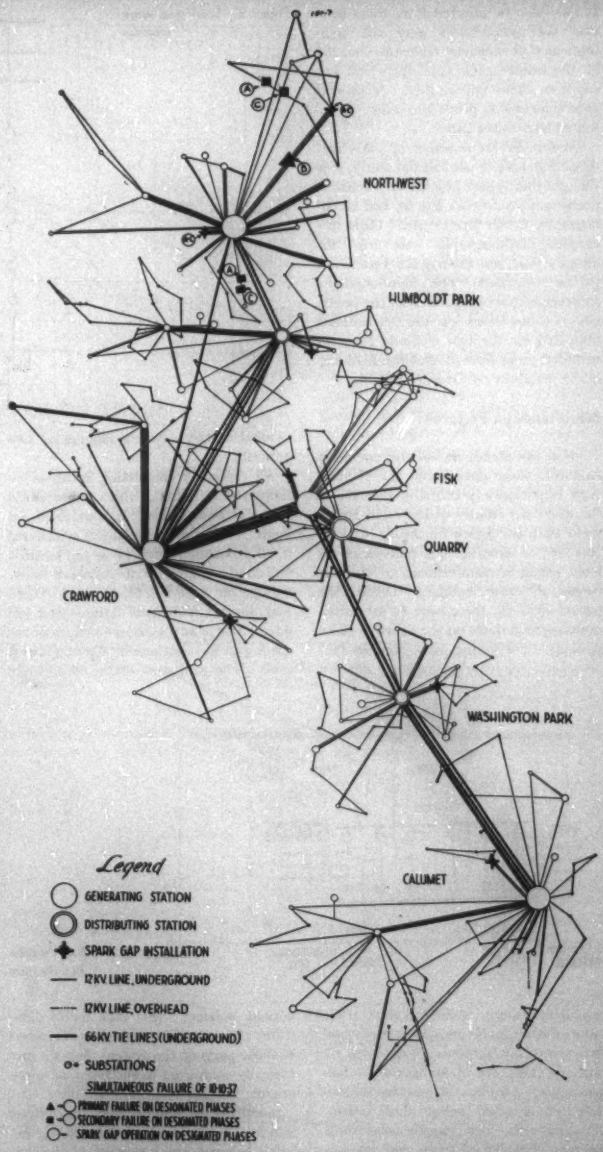
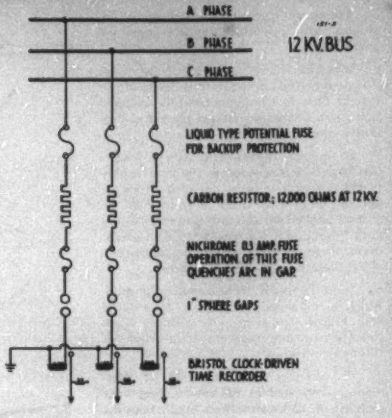


Figure 1. Chicago 12-kv system

It may also be inferred from these facts that the overvoltages were not high-frequency phenomena, since the time lag of the needle gaps apparently did not suppress them appreciably. More reliable evidence to prove the point is presented later in the paper.

Concerning the accuracy of the surge-recording devices used in the study, it is thought that sphere gaps are very reliable, needle gaps somewhat less so, and klydonographs rather inaccurate. Capacity-coupled klydonographs were tried for about a year, but the records were found to be worthless. The klydonographs were connected in parallel with the needle gaps. Comparison of the magnitudes indicated by the two methods for each recorded surge showed that the klydonograph installations were not reliable.

Figure 3. Spark-gap surge recorder


A PHASE
B PHASE
C PHASE
12 KV. BUS
LIQUID TYPE POTENTIAL FUSE FOR BACKUP PROTECTION
CARBON RESISTOR; 12,000 OHMS AT 12 KV.
NICHROME 0.3 AMP. FUSE OPERATION OF THIS FUSE QUENCHES ARC IN GAP
1" SPHERE GAPS
BRISTOL CLOCK-DRIVEN TIME RECORDER

Simultaneous Failures

From the standpoint of the operating engineer, surge phenomena are of practical importance principally because of the electrical failures of lines and equipment that are caused by them. The occurrence of simultaneous failures is the most common manifestation of troubles caused by surge voltages. During the period 1923–39, there were 54 sets of simultaneous failures on the Chicago 12-kv systems. Forty-nine were double failures, each involving one primary and one secondary failure, while five were triple failures, each involving one primary and two secondary failures. With one exception, every set of simultaneous failures involved a line. Apparatus failures that were involved include three generator armatures, four transformers, three reactors, three oil switches, and two bus structures.

During the period under consideration there were 1,240 primary failures on the Chicago 12-kv systems. Of these failures, 4.35 per cent caused simultaneous failures to occur, thus increasing the total number of 12-kv system failures by 4.84 per cent.

An especially interesting group of simultaneous failures, which occurred in the Northwest zone, is illustrated on figure 1. The primary failure, which was in all probability *B* phase at the location indicated, originated a transient overvoltage on *A* and *C* phases that caused four distinct additional failures and left a record on *A* and *C* phases at both of the spark-gap installations in the Northwest zone. The gaps were set at three times normal voltage. This case nicely illustrates the fact that surges are confined to those parts of the system that are metallically connected to the point of surge origin.

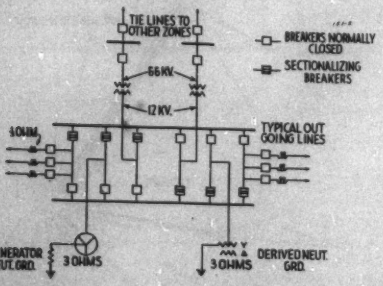


Figure 2. 12-kv station bus diagram

Simultaneous failures may be divided into four types based on the time lag existing between the inception of the primary and secondary failure. These are:

1. Secondary failure occurs within one or two cycles of the primary failure's inception, i.e., simultaneous with the initial surge caused by the primary failure.

2. Secondary failure occurs during the steady-state fault period of the primary failure.

3. Secondary failure occurs simultaneous with the clearing of the primary failure.

4. Secondary failure occurs a definite length of time after the clearing of the primary failure.

No oscillograph records of type 3 failures have been obtained in Chicago. It is reasonable to assume, however, that such failures are possible, and so this type has been included. Most simultaneous failures appear to be of type 1. This is inferred from the fact that the oscillograph records usually show both failures existing at the start of the record, the start being about 0.1 second (six cycles) after the inception of the primary failure. Many records of this type have been obtained. Type 2 failures are fairly common, while type 4 failures are rather rare. Type 2 is illustrated by the oscillogram in figure 7. On this record, a *B*-phase-to-ground cable fault, located three miles from the station, existed from *P* to *Q*. *B*-phase voltage is depressed while *A* and *C* voltages are above normal. At *Q* the secondary fault occurred on *C* phase to ground in another cable one-fourth mile from the station. For three cycles, *Q* to *R*, both faults existed simultaneously. At *R*, the primary fault cleared, leaving the *C*-phase fault on the system. A few records of type 4 simultaneous failures have been obtained on the 12-kv system, but unfortunately these records are not suitable for reproduction. An entirely similar case is, however, available from the records of the 9-kv 25-cycle system and is shown in figure 8. The primary fault was on *A* phase, *S* to *T*. This fault cleared at *T* and the system was normal

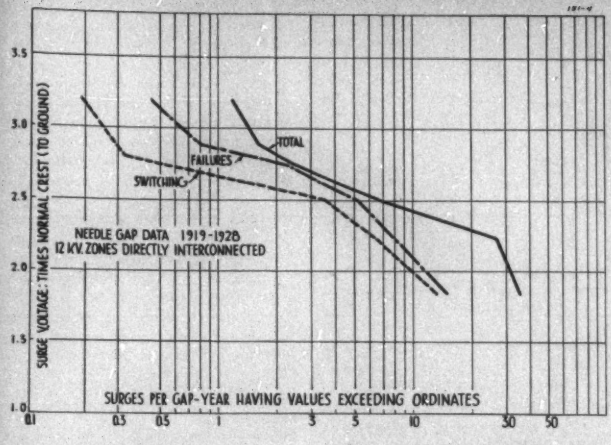


Figure 4. Surge data for 12-kv system, 1919–28

for 1.6 seconds, T to U. At U, the secondary fault occurred on B phase to ground, continuing to V, at which point it was cleared from the system. This interesting record clearly shows that a very definite time lag may occur between the period during which insulation is overstressed and the actual time of its electrical breakdown.

Staged Tests

It is easier to grasp the significance of the test data if the postulated theory of surge production is first understood. The discussion will be confined to surges caused by single line-to-ground faults, which are the highest occurring on the Chicago 12-kv system. The overvoltage resulting from the fault may properly be considered in three parts, as follows.

A. The "Make" Transient

If the initiation of the fault is a simple "make" operation involving no intermittent arcing, then on the approximation that all circuit elements are linear the effect is precisely as though the fault were replaced by a single-phase voltage generator of zero impedance, generating a cancellation voltage that is at all times exactly equal and opposite to the unfaulted steady-state voltage at the fault. The actual voltages and currents in all parts of the network may be obtained by superposing on the unfaulted steady-state condition the transient and ensuring steady state of the network as fed by the cancellation generator.

Figure 9 shows a schematic three-phase diagram of the 12-kv system at a generating station. There are n outgoing lines, each equipped with one-half-ohm reactors. The simplification of zero interphase coupling is introduced and the n conductors and reactors on each phase are grouped to give single parallel equivalents.

A fault is applied on C phase of one of the lines. The cancellation voltage, which may be thought of as a traveling wave if the fault is fairly remote from the station, travels into the station, where it initiates a complex transient whose frequencies are determined mainly by the inductance of the faulted line's reactor and the total system capacitance to ground. Let E be the normal phase-to-ground peak voltage. The theoretical limiting value for the cancellation transient at the bus, assuming infinite neutral impedance, is $4E$ if there are no outgoing lines other than the faulted line, and $2E$ if there are a large number of outgoing lines. This latter value is reduced slightly by the presence of a neutral grounding impedance of a few ohms, the reduction being greater with a resistance ground than with an inductance ground. In any case, the transient resulting from the incoming wave appears almost symmetrically on all three phases of the system. The resulting system overvoltage is the superposition of this cancellation wave and the normal steady state. It is reasonable to expect that for the Chicago

Figure 5. Surge data for 12-kv system, 1932–38

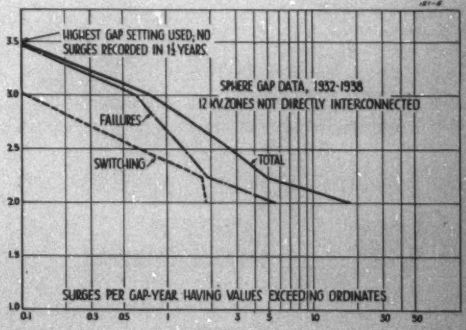
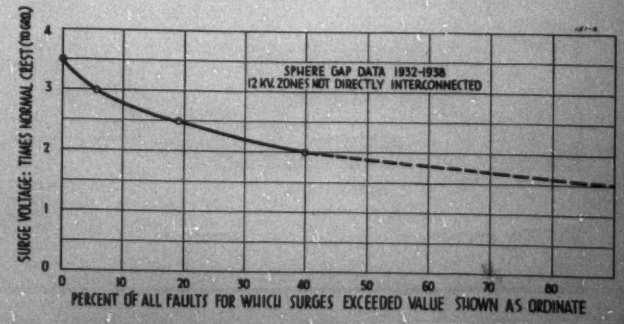

HIGHEST GAP SETTING USED; NO SURGES RECORDED IN 1½ YEARS
SPHERE GAP DATA, 1932-1938
12 KV. ZONES NOT DIRECTLY INTERCONNECTED
FAILURES
SWITCHING
TOTAL
SURGES PER GAP-YEAR HAVING VALUES EXCEEDING ORDINATES

Figure 6 (below). Correlation of surges and failures


SURGE VOLTAGE: TIMES NORMAL CREST (TO GND.)
SPHERE GAP DATA 1932-1938
12 KV. ZONES NOT DIRECTLY INTERCONNECTED
PERCENT OF ALL FAULTS FOR WHICH SURGES EXCEEDED VALUE SHOWN AS ORDINATE

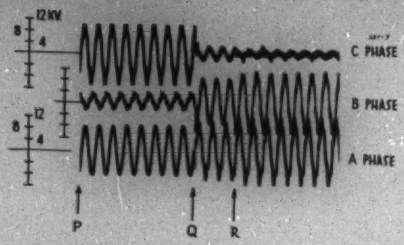


Figure 7. Simultaneous failure, type 2

P to *Q*: primary fault on *B* phase

Q: secondary fault initiated on *C* phase of another line; *B*-phase fault still on first line

Q to *R*: faults coexisting on *B* phase and *C* phase

R: *B*-phase fault cleared; *C*-phase fault still on but cleared later

system this surge, which constitutes the first portion or "make" transient of the system overvoltage, should not exceed $3.5E$. This value is obtained by adding a maximum expected cancellation transient of $2.5E$ to the normal steady-state value of E.

B. The Steady-State Fault Condition

After the transient of the applied cancellation wave has died out, the network conditions may be pictured as the sum of the normal steady state and the steady state of the cancellation generator. More simply, however, the conditions are obtained directly by the methods of symmetrical components. It is easily verified that for Chicago conditions with generator neutral grounding, which is three ohms resistive, or derived neutral grounding, which is three ohms inductive, the steady-state overvoltage on the unfaulted phases will not exceed $\sqrt{3}E$.

C. The "Break" Transient

The surge that results from the clearing of a fault is obtained precisely as in the fault initiation case except that a cancellation current, instead of a cancellation voltage, is "injected" at the fault. In this case, the transient effects the transition from a peak voltage of $\sqrt{3}E$ down to E whereas the reverse is true in the fault initiation case. It is reasonable to expect, therefore, greater total transient voltages on the fault "make" than on the break, assuming in all cases no restriking of the arc.

Some complete records of 12-kv surges were obtained in a series of 15 staged fault tests made at Northwest station in Chicago. The faults were thrown directly on the system, which was in normal everyday service. In each of the tests, a line-to-ground fault was applied by a special breaker to *A* phase of one outgoing line on the line side of the one-half-ohm line reactor. In some of the tests the 12-kv station bus was sectionalized to split the Northwest zone 12-kv system into two entirely independent parts (refer to figure 2). In the remainder of the tests the two busses were tied, which is the normal system setup. Four cycles prior to the application of the fault, the following oscillographs were initiated:

1. Cathode-ray oscillograph capacitatively coupled to *C* phase of the 12-kv station bus. Since the faults were applied on *A* phase, the transient overvoltages would appear on *C* and *B* phases. A film speed of six inches per cycle was used.

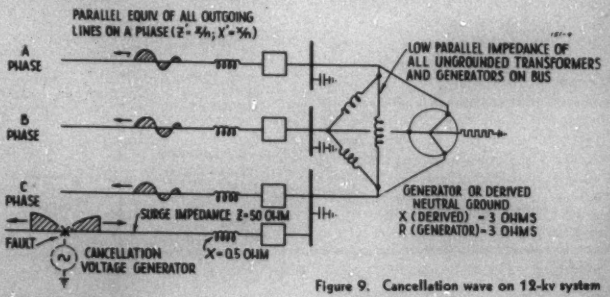

PARALLEL EQUIV OF ALL OUTGOING LINES ON A PHASE (Z'=⅝; X'=⅝)
A PHASE
B PHASE
C PHASE
FAULT
SURGE IMPEDANCE Z=50 OHM
X=0.5 OHM
CANCELLATION VOLTAGE GENERATOR
LOW PARALLEL IMPEDANCE OF ALL UNGROUNDED TRANSFORMERS AND GENERATORS ON BUS
GENERATOR OR DERIVED NEUTRAL GROUND
X (DERIVED) = 3 OHMS
R (GENERATOR)=3 OHMS

Figure 9. Cancellation wave on 12-kv system

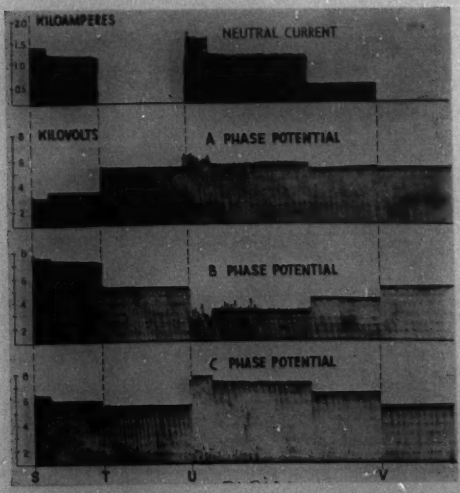


Figure 8. Simultaneous failure, type 4

S to *T*: primary fault on *A* phase

T: fault cleared, system normal from *T* to *U*

U to *V*: secondary fault on *B* phase

2. Magnetic oscillograph to record *A*, *B*, and *C* phase potentials on both sections of the 12-kv station bus.

3. Magnetic oscillograph to record the current in the system neutral and *A*-phase fault current.

The *C*-phase potentials recorded by the cathode-ray oscillograph in two of the tests are shown in figure 10. The *A*-phase fault in these two cases consisted of a one-inch arc in air between copper bars. Eight cycles after the initiation of the faults they were cleared by the line breaker. Under each of the *C*-phase potential records, there is entered the cancellation potential, which starts at the time of fault and is equal and opposite to the normal potential on *A* phase. The transient resulting from the application of the cancellation wave is seen to last about one cycle. The first portion of the transient, corresponding to the first half cycle of the natural frequency of this transient, is seen to correlate, as it should,

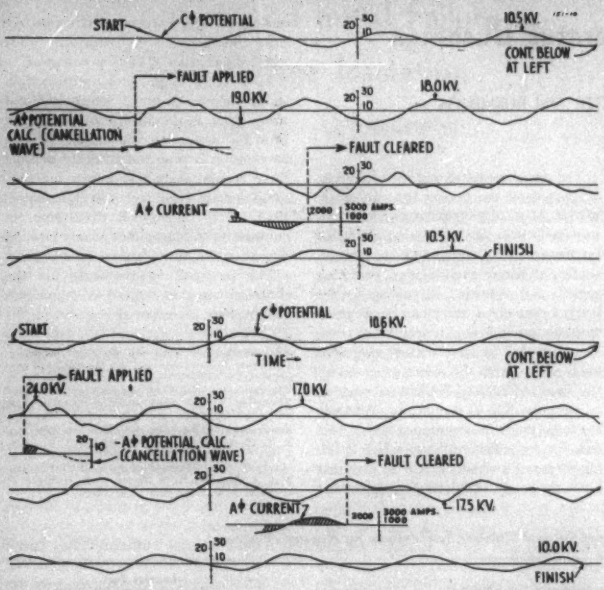


Figure 10. Oscillograms of staged fault tests

a (above)—12-kv zone sectionalized
b (below)—12-kv zone not sectionalized

exactly in both magnitude and polarity with the cancellation potential at the time of fault.

For the test in figure 10*a* the 12-kv bus was sectionalized, resulting in a higher transient frequency than in 10*b* where the systems were tied. The transient frequency did not exceed 500 cycles per second in any of the tests. The absence of higher frequencies, for the detection of which the cathode-ray oscillograph was well adapted, checks the conclusion derived from the spark-gap studies.

The overvoltage during the steady state of the fault is seen to be very close to $\sqrt{3}E$ as expected.

The transient overvoltage accompanying the clearing of the fault was less than $\sqrt{3}E$ in both cases shown in figure 10. Intermittent arcing is not indicated by any of the records obtained. The fault current during the break period is indicated under both oscillograms of figure 10. As is to be expected, the break occurred near a current zero.

The results of the remaining 13 fault tests are in accordance with the two cases described. In no case did the break transient give voltages in excess of $\sqrt{3}E$ and in no case was the faulted steady-state overvoltage in excess of $\sqrt{3}E$. In 5 of the 15 tests a surge voltage of between 24 and 26 kv ($2.27E$ to $2.45E$) was measured within one cycle of the initiation of the fault. In all of these cases the grounding was of the derived neutral type. In four tests with generator (resistance) grounding, the maximum surge potential did not exceed $2E$.

Summary

The highest transient overvoltages on the Chicago 12-kv system occur at the inception of single line-to-ground faults. They may be thought of as resulting from the superposition of a "cancellation wave" on the normal steady-state voltage of the system. The transient is not a high-frequency phenomenon and is not generated by an "intermittent-arcing" mechanism. The maximum crest values reached are in the neighborhood of $3.5E$ and persist for only the first cycle or two of the fault. For the remainder of the fault, including the clearance switching, the maximum overvoltage is $\sqrt{3}E$. These overvoltages may cause secondary (simultaneous) failures in any part of the connected system where the insulation is unable to withstand them for the short times they persist.

Report on Apparatus Bushings

AIEE JOINT COMMITTEE ON BUSHINGS

THE AIEE joint committee on bushings presented a report at the 1940 winter convention in which the committee proposed uniform requirements for the electrical characteristics of outdoor apparatus bushings. Since that time the committee has continued its work and has now completed a tabulation of proposed requirements for indoor and outdoor apparatus bushings rated 2,500 volts and higher.

The scope of the committee includes bushings for circuit breakers, transformers, regulators, and similar apparatus. It does not include wall and roof bushings potheads, and insulators for back-connected disconnecting switches.

The recommendations of the committee are based on the theory that an ample margin of insulation strength should be provided above the voltage to which the bushings may be subjected in service, including dynamic overvoltages, switching surges, and lightning surges up to the level of protection which can be provided with modern lightning protective devices. The impulse characteristics suggested are in accord with the values proposed by the joint AIEE-EEI-NEMA committee on co-ordination of insulation. All tests are to be made in accordance with a test code for apparatus bushings which is being prepared and which will be included in a proposed standard for apparatus bushings. The recommended values are expressed in terms of "withstand voltages" rather than "flashover voltages."

In order to avoid conflict with certain small indoor bushings which will not meet these requirements and to allow time for modifying the design of such bushings it is proposed to delay making these requirements mandatory for such small indoor bushings until January 1, 1943. It is understood that these requirements will be applied to any new design or redesigns made prior to that time.

The proposed requirements for the electrical characteristics of apparatus bushings are given in table I.

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Personnel of AIEE joint committee on bushings: R. T. Henry, *chairman*; F. S. Brown, J. E. Clem, I. W. Gross, L. H. Hill, J. T. Lusignan, A. C. Monteith, J. R. North, E. Peipho, M. S. Oldacre, A. J. A. Peterson, R. E. Pierce, C. B. Springer, P. C. Turk, F. J. Vogel, and L. Wetherill.

Table I Proposed Standard Withstand Test Voltages for Apparatus Bushings

Insulation Classification[c] (Kv)	Low-Frequency Test RMS Kv[b] Outdoor Bushings: Large Apparatus[e] 1 Min Dry	Large Apparatus[e] 10 Sec Wet	Small Apparatus[f] 1 Min Dry	Small Apparatus[f] 10 Sec Wet	Indoor[g] Bushings 1 Min[c] Dry	Impulse Test 1.5x40-Microsecond Full Wave Crest Kv[b,d] Outdoor Bushings: Large[e] Apparatus	Small[f] Apparatus	Indoor[g] Bushings
1.2			10	6		30		
2.5	21	20	15	13	20	60	45	45
5.0	27	24	21	20	24	75	60	60
8.7	35	30	27	24	30	95	75	75
15	50	45	35	30	45[h]	110	95	110[h]
23	70	60	70	60	60	150	150	150
34.5	95	80	95	80	80	200	200	200
46	120	100	120	100		250	250	
69	175	145				350		
92	225	190				450		
115	280	230				550		
138	335	275				650		
161	385	315				750		
196	465	385				900		
230	545	445				1,050		
287.5	680	555				1,300		
345	810	665				1,550		

NOTES: [c] Bushings of a given insulation classification are in general recommended for apparatus having a rating up to and including the insulation classification of the bushing and may be used for apparatus of a higher voltage rating when adequate for the particular application.

[b] All values are withstand test values without negative tolerance.

[c] Wet test values are not assigned to indoor bushings.

[d] Either positive or negative waves may be used—whichever gives the lower value.

[e] Bushings for use in large apparatus are those intended for use in transformers rated above 500 kva, outdoor circuit breakers, and other apparatus of corresponding importance.

[f] Bushings for use in small apparatus are those intended for use in transformers rated 500 kva and less and other apparatus of corresponding importance.

[g] Bushings for use in indoor apparatus are those intended for use in indoor-type circuit breakers, instrument transformers, and other indoor apparatus except dry-type instrument transformers, air-cooled transformers, air-cooled regulators, and bushings used primarily for mechanical protection of insulated cable leads.

[h] Bushings for small indoor apparatus may be supplied to withstand a low-frequency test of 38 kv and an impulse test of 95 kv.

The Detection of Initial Failure in High-Voltage Insulation

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Introduction

IN a series of accelerated life tests[1] on laboratory samples of impregnated-paper insulation of the type commonly used in high-voltage cables, certain methods have been employed for limiting the breakdown current and thereby the attendant burning of the insulation. In this way it has been found possible to obtain partial failures in which the breakdown is limited to only a portion of the insulation wall, say one-half or one-third of the total number of layers, the remaining layers being apparently unaffected. In these partial failures, the burning is very slight and it is possible to obtain a very good idea as to the location of the initial point of failure and the nature of its subsequent progress. With one of the methods used it has been possible on occasion to limit the breakdown to only two layers of paper and to study the extension of the failure through adjacent layers. The method gives great promise for the study of the mechanism of breakdown under laboratory conditions. In this paper we are reporting some of the preliminary results of a more extended program of study still under way.

Probably the condition most conducive to the beginnings of failure under normal conditions of service is the presence of gas bubbles, pockets, or layers within the body of the insulation. Potential gradients at which ionization can begin in such gas pockets or layers are often exceeded in equipment for only moderately high voltages. Gas layers in the insulation circuit may be caused by imperfect impregnation, or as the result of bending or other mechanical strains in the normal processes of manufacture, transportation, and installation. In other cases gas spaces may result from the temperature variations attendant upon load changes. The accelerated life tests already referred to have indicated still a further cause of gas liberation, namely high-voltage stress on the oil layers or other free oil in impregnated-paper insulation, such as the channels between successive turns of paper tape. Study of the partial failures referred to clearly indicates that initial failure usually starts in the oil channel and is accompanied by the evolution of gas.

Under alternating stress gaseous ionization and other initial discharges occur first on the crests of the alternate half waves. This gives the discharges an impulse character so that in conjunction with the capacitance and inductance of the high-voltage circuit the discharges take on an oscillatory character. This fact has afforded a simple means of detecting the presence of such discharges and has been utilized almost exclusively by those who have studied the phenomenon.

Ripples on the crests of a-c voltage waves due to gas discharges were apparently first shown by Edward Bennett,[2] using the electromagnetic oscillograph. With the development of the cathode-ray oscilloscope, visual observation of the ripples is a simple matter, and this instrument is commonly used as a qualitative detector in all studies of this character. The earlier studies of Paine[3] and coworkers are well known. The possibility of more sensitive and quantitative studies has been shown by Arman and Starr,[4] the distinguishing characteristic of whose work is a bridge, filter, and amplifier circuit free from disturbance due to local discharges in the high-voltage circuit and extraneous to the specimen under study.

Measuring Equipment

In the present work the method of Arman and Starr, with certain modifications and extensions, has been used for the detection of initial internal gaseous discharge and the quantitative study of the subsequent stages of the discharge, first on impregnated-paper insulation originally containing no free gas, and also on several types of insulating wall with gas pockets and oil channels of controlled dimensions.

Bridges

Two types of bridge have been used. The first for voltages up to 30 kv was the modified Schering bridge due to Whitehead.[5] This bridge was in constant use for the measurement of power factor in the series of accelerated life studies on impregnated-paper insulation of cable type already referred to. At regular intervals in the life runs of these specimens the detection circuit of the present research was connected to the Schering bridge, following the periodic measurement of 60-cycle power factor in the life runs. In this way it was possible to fix within a few hours the time at which internal ionization began and in some measure to correlate the progress of internal ionization with changes in 60-cycle power factor and applied voltage.

For closer study of internal discharges, it appeared desirable to work with thinner specimens in which the critical gradients would be reached with the specimen continuously in the bridge circuit. Accordingly the simplified form of Schering bridge shown in figure 1 was constructed. C_x is the specimen and C_a is the air capacitor. Auxiliary studies indicated that up to ten kilovolts, the limit of bridge operation, the high-voltage circuit including the air capacitor was free from internal discharges.

Bridge Transformer

The detection equipment was connected to either of the bridges through a high-quality bridge transformer, with electrostatic shielding between the pri-

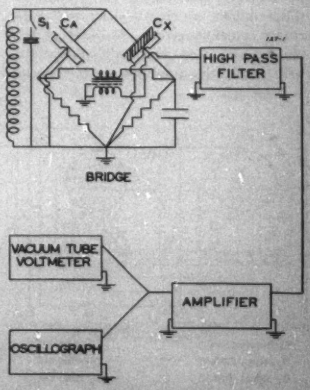

Figure 1. Discharge bridge circuit and connection of apparatus

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1. For all numbered references, see list at end of paper.

mary and secondary windings, both of which were capacitively balanced with respect to ground. This permitted one end of the output winding of the transformer to be grounded without disturbing the symmetry of the bridge circuit. This is important because it permits the grounding of one side of the whole amplifying and detecting circuit, thereby permitting that the whole circuit be enclosed in a grounded shield. Circuit changes on the output side of the transformer thus have no influence on the balance of the bridge. The voltage ratio of the transformer was measured between 1 and 50 kilocycles and found to be closely uniform up to about seven kilocycles, and to decrease somewhat beyond. The over-all impedance ratio of the transformer based on its turn ratio was 4.4 to 1 which brought about an impedance match between the bridge and the high-pass filter.

Filter

A filter having three full sections was adopted. The cutoff frequency, 3,600 cycles, was chosen because it was low enough to pass the band of oscillations due to internal discharges and high enough to reject any high harmonics of the 60-cycle charging current. The terminal impedance at each end was 5,500 ohms. Impedance matching at the input end of the filter was accomplished by the bridge output transformer. Impedance matching with the amplifier was effected by placing a noninductive resistor of 5,500 ohms across the filter.

Amplifier

A resistance-capacitance coupled amplifier was inserted between the filter and the detector (see figure 1). Details of the amplifier are shown in figure 2 with circuit constants given. At 10,000 cycles, the frequency at which all calibrations were made, the amplification factor was

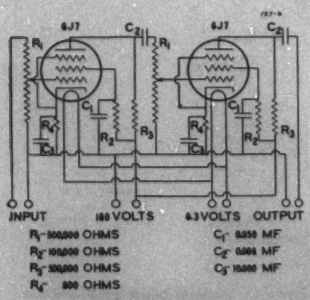


Figure 2. Amplifier

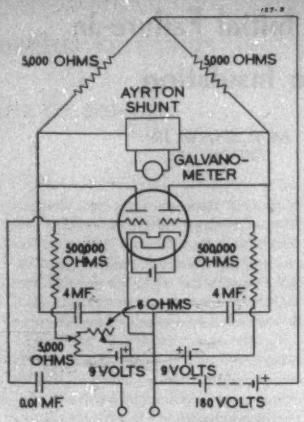


Figure 3. Circuit diagram of balanced vacuum tube voltmeter using type 6N7 tube

4,700. As a function of the input voltage saturation took place at an input voltage of 5.5 millivolts. Consequently all readings recorded were obtained with input voltage to the amplifier of five millivolts or less.

Detectors

A standard model of a well-known make of cathode-ray oscilloscope was used for qualitative measurements. An amplifier of gain 40 was incorporated in the oscilloscope. This, in conjunction with the external amplifier made it possible to realize an over-all gain of 40×4,700, or 188,000 at 10,000 cycles. This instrument is extremely useful, permitting ready and rapid visual observation of conditions obtaining in the circuit.

For quantitative measurements a balanced vacuum tube voltmeter as indicated in figure 3 was used. This arrangement is independent of small changes of battery voltage and the combination of duplex tube, decade resistance boxes, and Ayrton shunt for the galvanometer, results in a very sensitive quantitative instrument. The calibration of the meter with galvanometer of 120 megohms sensitivity with various settings of the shunt was found to hold over the range 60 cycles to 50 kilocycles. The voltage required for one centimeter deflection at maximum sensitivity was 13,000 microvolts. The over-all amplification factor between the input of the bridge transformer and the output of the amplifier as function of frequency may be had from the data in table I. At ten kilocycles the over-all amplification factor was 1,830. Hence a voltage of 13,000/1,830 or 7.1 microvolts gave a galvanometer deflection of one centimeter. In figure 4 the voltage for one centimeter deflection is plotted over the range 1 to 50 kilocycles.

Tests and Calibration of Equipment

Ten-Kilovolt Discharge Detection Bridge

A first necessary step in the use of this method is to balance the bridge for minimum effect in the detection apparatus, of local high-frequency discharges external to the specimen itself. Accordingly a small discharge gap consisting of a few layers of varnished cambric between two brass electrodes was connected between the bridge and the high side of the supply transformer, as shown in figure 1. The primary voltage is increased until discharge occurs in the gap, the latter being adjusted for discharge at relatively low voltage. The detecting circuit is then connected using the oscilloscope as indicator. The bridge is then balanced so as to bring to a minimum the signal on the screen of the oscilloscope. This minimum could be made practically zero, even though the ionization in the gap was strong enough to be audible several feet away.

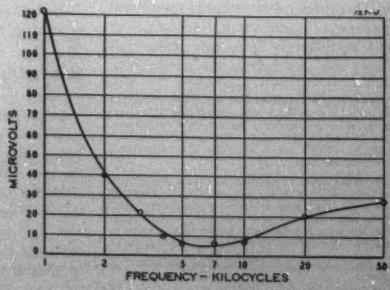


Figure 4. Voltage necessary at bridge terminals to cause one centimeter galvanometer deflection

In this method it is to be noted that stress is applied to the specimen under test at 60 cycles but that only a fraction of the total discharge current over a comparatively narrow band of frequencies reaches the detecting circuit. This fraction passes through the several elements of the complete circuit before reaching the final detecting instrument. It seemed advisable, therefore, to test the over-all sensitivity and accuracy of the equipment by comparison with the known properties of the breakdown strength of air in thin layers as related to pressure, through Paschen's law. The apparatus was a guarded capacitor consisting of a layer of air backed by a layer of glass for preventing complete breakdown. For the range of pressure between 15 centimeters and 76 centimeters Hg, the voltage stresses for initial ionization, as determined by the equipment, and as computed from Paschen's law are shown in figure 5 for the temperatures indicated. In figure 6, the critical stress as a function of the electrode spacing is shown in the solid curve; for comparison, the experimental results of Dubsky[6] on thin air films, are also plotted.

30-Kv Schering Bridge

The large physical size of this bridge resulted in enough pickup of extraneous high-frequency disturbance to serve as a guide in the preliminary balance without recourse to a discharge gap. The effect of the external discharges was readily balanced out by adjustment of the resistance arms and the variable capacitor.

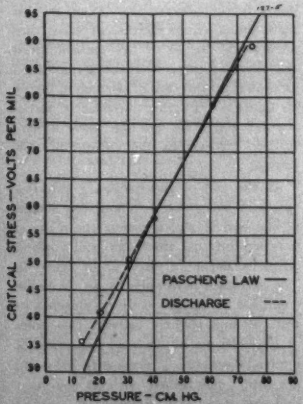


Figure 5. Critical stress for gaseous discharge between parallel plates as detected by discharge bridge and as function of pressure

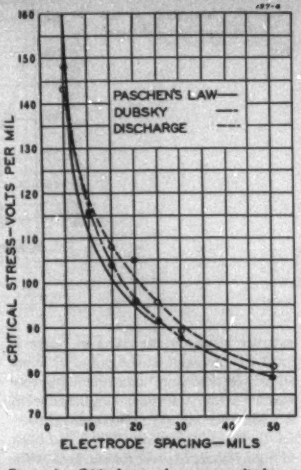


Figure 6. Critical stress for gaseous discharge between parallel plates as detected by discharge bridge and as function of separation of plates

In this condition the bridge could be used for the study of initial discharges in specimens of impregnated-paper cable insulation on life test and at higher voltage gradients in these life specimens than possible with the ten-kilovolt bridge.

Experimental Results

The method was applied to several types of insulation as follows: (*A*) laboratory specimens of impregnated paper as found in high-voltage cables, and originally free from gas bubbles or pockets; (*B*) single oil channels as found in cable insulation; (*C*) channels and bubbles of air of known dimensions, and subject to visual observation. The general method of test was the determination of the voltage gradient at which internal gaseous discharge begins and the increase in the "volume" of the latter with increasing gradient. At an early point it was found that the elapsed time of application of stress may have an important influence on both the critical discharge stress and on the "volume" of discharge at sustained high stress. The readings of the detecting instrument are obviously proportional to an integrated value of a product of the number of discharge areas and the intensity of discharge current in each area. In what follows the word "volume" has been used to indicate this integrated product.

(A). Cable Insulation

In the accelerated life tests on standard types of impregnated-paper insulation, the test samples consisted of 16 layers of 0.005-inch wood pulp paper one inch wide, spiraled cable fashion on one-inch diameter smooth brass tubes with 33 1/3 per cent overlay and a butt spacing of approximately 1/64 inch. These samples were dried and impregnated with a low-viscosity high-grade cable oil in the usual way, and tested to break down under the impregnating oil. The accelerated step-up life test started at an average stress of 400 volts per mil on the specimen and the applied stress was increased by 3.12 per cent every four hours, thus giving a geometric increase such as to bring the stress to 700 volts per mil within three days. Under this program, the life of the specimen was from 60 to 80 hours, and the breakdown gradients from 600 to 800 volts per mil, at 50 to 65 kv on the test transformer.[1]

At four-hour intervals the life test was interrupted for the measurement of power factor over the range 100 to 400 volts per mil. Following the power-factor measurement, the galvanometer was cut out of

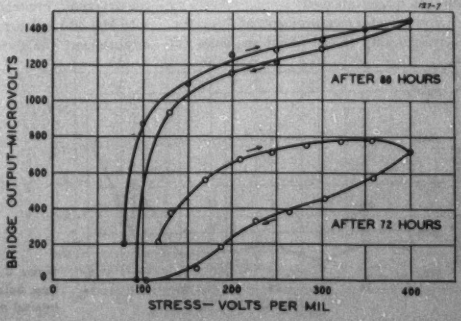


Figure 7. Ionization in impregnated-paper insulation

the Schering bridge and the discharge equipment connected. The bridge was then balanced for a negligible minimum reading of the discharge equipment due to external discharges in the high-voltage wiring, up to a voltage somewhat below that at which internal discharges begin in the sample. The equipment was then ready for observation.

First observation was made on the specimen after it had been on test for 24 hours reaching a stress of 467 volts per mil. No internal discharge was found at this point nor at subsequent intervals of 12 hours up to 60 hours with a final stress of 618 volts per mil. Positive readings of internal discharge were first observed after the specimen had been on test for 72 hours with a final stress of 679 volts per mil. In these observations it is to be recalled that the specimen was removed from the life test voltage, power factor and internal discharge being measured over the range 100 to 400 volts per mil.

The relation between internal discharge and stress, finally found after 72 hours of test, is shown in the lower curve of figure 7. As will be seen the volume of discharge increases with the stress, tending, however, to a maximum value and then to a somewhat lower value at the maximum stress of 400 volts per mil. The volume of discharge on decreasing stress is seen to be markedly lower than for increasing stress In another test, the stress was held constant at 400 volts per mil and it was found that the volume of discharge decreased with time and ultimately ceased entirely. This indicates that when internal discharge occurs, it will continue at substantially lower values of applied stress. However, there is a lower value of stress at which there will be a decrease and final disappearance of the volume of internal discharge. This decrease is probably due to gas absorption and oil sealing, or perhaps to internal burning or carbonization, short-circuiting the gas spaces involved.

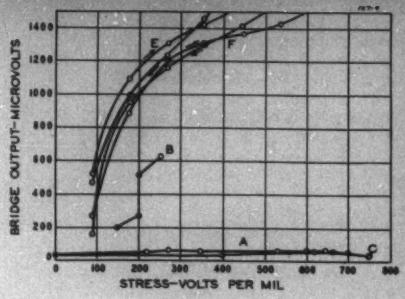
Power-factor measurements at 60 cycles corresponding to the above sequence of tests are given on the curve of figure 8. Point 7 is the value at the end of 72 hours before the discharge measurements were made. After sustained application at 400 volts per mil with cessation of internal discharge, the specimen was put back on high-voltage life test for one hour, then removed, and tested again for power factor and internal discharge. The power-factor value is given at point 8 and there was no evidence of internal discharge. The specimen was then returned to life test for eight hours with a final stress of 722 volts per mil, and during this interval two power-factor readings indicated the increase shown beyond point 8 in figure 8. The internal discharge now followed the upper curve of figure 7, which has the same general shape but greater magnitude than the earlier curve. The influence of time is still present though not so marked. It appears probable that owing to the higher stress, deterioration and new internal discharges are increasing more rapidly than the decreases shown in the tests at lower stress. On return to life test after these measurements, the specimen failed within two hours.

In order to be independent of the above life tests and to reach higher stresses at lower over-all voltage, similar specimens with only half the thickness of wall, were constructed, impregnated, and tested with the 30-kv Schering bridge. In this arrangement the stress could be carried to 800 volts per mil and internal discharge measurements made at all stresses up to this figure without interruption.

The specimen was first carried slowly up to 700 volts per mil with the result shown in curve *A* of figure 9. The level of discharge due to external influence is seen to be very low and uniform in the whole range of stress. After 12 hours rest, the power-factor stress relation shown by curve *A* of figure 10 was taken. The increase in power factor thus found seems to indicate that internal discharges are taking place in the specimen. None such were found however until after ten minutes' application of the maximum stress of 700 volts per mil, at which point a violent indication of internal discharge was found. The voltage was immediately removed and the specimen given a ten-minute rest. It was then found that internal discharge started at 100 volts per mil, with a further increase as indicated by curve *B* of figure 9. A power-factor observation taken at this point indicated an increase of value, and during the period of this measurement the volume of internal discharge increased as shown by the dotted portion of curve *B*, figure 9. Further increase of stress beyond 200 volts per mil gave a still further increase in the volume of discharge.

At the end of the foregoing test, the specimen was given a 70-hour rest period at the end of which period the relation between internal discharge and applied stress is shown in curve *C* of figure 9. The specimen is apparently in the same condition as when it was first subjected to test, perhaps slightly better. One hour at 700 volts per mil gave no indication of internal discharge. Increase to 750 volts per mil, maintained for 55 minutes, brought about the renewal of internal discharge. The voltage was immediately reduced to zero and then gradually reapplied, discharge beginning at 620 volts

Figure 9. Ionization in impregnated-paper half-wall specimen



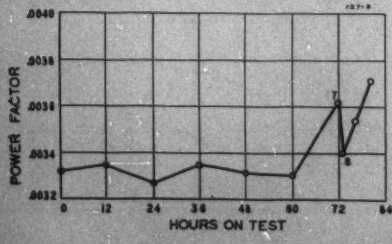


Figure 8. Power-factor variation before and after initial internal discharge

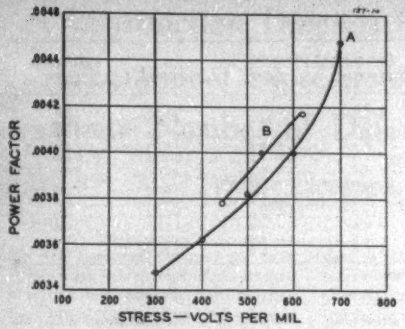


Figure 10. Power factor of half-wall specimen

per mil. The power factor had also increased (see curve *B* of figure 10).

Two discharge stress runs were then made, with a short-time interval between runs. The results are shown in curves *E* and *F* of figure 9. Note that the volume of discharge in the second run was less than in the first, suggesting a slight recovery in the interval between runs.

After another 12-hour rest period, the specimen was again found to be free of internal discharge after 700 volts per mil, maintained for eight hours. The stress was then increased to 750 volts per mil when internal discharge began immediately, but the specimen failed before a quantitative measurement could be taken.

(B). Oil Channels in Small Specimens

In order to investigate the value of stress at which internal discharges begin in an oil channel in impregnated paper, a group of two- and three-layer impregnated-paper specimens were prepared and tested between horizontal, parallel, polished brass plates. The three-layer specimens consisted of two sheets of impregnated paper and a third sheet in which a slit was made. In the two-layer specimens, one layer was continuous and the other contained a slit. The slits were the same width (0.0156 inch) as the oil channels in the life test specimen referred to above; their length was three inches. Drying and impregnation were in accordance with three-layer and two-layer specimens referred to above.

Preliminary tests were made with three-layer and two-layer specimens of continuous sheets of paper, and it was found that these could be carried to 1,100 and to 1,200 volts per mil respectively, and maintained for six hours without evidence of internal discharge.

For testing the specimens containing slit papers forming oil channels, the following schedule was used: (*a*) 15 minutes at 1,000 volts per mil in the oil channel (ratio of dielectric constants, impregnated paper to oil: 2); (*b*) three per cent per minute increase in stress to 1,600 volts per mil in channel; (*c*) five per cent increase in stress at five-minute intervals from 1,600 volts per mil to incipient failure.

This accelerated schedule is necessary to eliminate the influence of time found in the earlier studies. In two two-layer specimens, initial internal discharge was found at 1,530 and at 1,860 volts per mil in the oil channel; in the three-layer specimens the values found were 1,600 and 1,630 volts per mil. These values are somewhat higher than those reported by Whitehead[1] which were in the range 1,350 to 1,550 volts per mil. In the latter case, however, the specimens were under high stress a much longer time. In the present case all of the incipient discharges eventually produced punctures originating in the oil channel.

(C). Tests on Air Bubbles in Oil Channels

A special test cell permitted the insertion of air bubbles in the oil channel in a slit in impregnated paper. Visual observation was possible through the upper electrode, consisting of a salt solution in a tray with plate glass bottom. Special provisions permitted the operation of the cell up to ten kilovolts without disturbance in the detecting circuit due to discharges from the guard circuit.

With paper in place, the whole apparatus was evacuated to one millimeter Hg at 40 degrees centigrade for two hours, at which point all gas has ceased to come out of the oil. A test was then made at low stress which showed the absence of discharges. The upper electrode was then carefully moved to one side, exposing the channel. An air bubble was then introduced by means of an eye dropper, and the electrode then brought back into place.

The gaseous discharge as a function of applied stress was measured on bubbles of lengths, 47.2, 98.5, and 132 mils, and width of 15.6 mils. The quantitative results for bubbles of the same length varied somewhat but certain characteristics were invariably repeated. Three curves, for temperature 40 degrees centigrade are shown in figure 11. For shorter bubbles, the discharge in general increases with increasing stress and decreases with decreasing stress. For the longer bubbles the conditions become erratic and no definite behavior is indicated which may be correlated with the results on the cable specimens. Using the results on the shorter bubbles as a measure, it is suggested that the initial discharges in the cable specimens begin bubbles less than 0.1 inch in length, and 0.03 inch in width.

Discussion

The peculiar relationships between internal discharge, stress, and time noted in connection with the cable specimens may perhaps be best explained in terms of the frequent observation that first evidences of breakdown occur in the oil

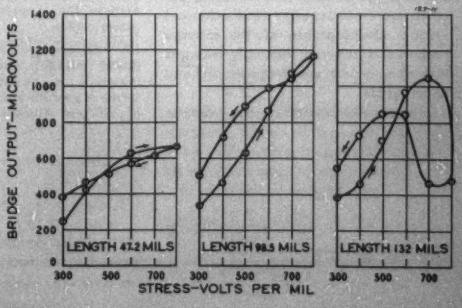


Figure 11. Ionization in air bubbles

channels and that the initial stages of this breakdown are accompanied by the liberation of gas. At initial discharge in the oil, corona formation results in the evolution of gas and polymerization. Once a bubble of gas is formed, it may be ionized at a value of stress much lower than that causing the original discharge. The gas bubble, however, is not stable and may be reabsorbed into the oil. This is responsible for the variation with time of the intensity or volume of discharge, and also for the complete recovery following a long rest period. The healing effect of time without stress is particularly noticeable in the thicker cable specimens on life test at higher stresses. Interruption of the high stress and subsequent measurement of power factor at very much lower stress provides opportunity for healing action due to gas absorption. It also probably accounts for the steady decrease of internal discharge even when stress is applied to the specimen, when this stress is substantially lower than that at which the internal discharge was first initiated.

The peculiar loops showing decreases of volume of discharge with increasing stress and vice versa noticed in the impregnated paper and air bubble tests may perhaps be explained as due to variations in pressure in gas pockets. A more or less rapid increase in pressure causing a reduction in the volume of discharge is followed by a slow release of pressure with corresponding increase in the volume of discharge.

The increase in the strength of the insulation with successive discharge cycles may possibly be explained by the process of polymerization. The wax which replaces the oil has high dielectric strength and prevents this particular spot from ionizing again. With increasing stress, discharge will first occur at a different point. It also appears possible that surface discharges, tree patterns, and the like, may at times result in the short circuit of a gas pocket, thus reducing the ionizing stress and causing a reduction and possible disappearance of the internal discharge, which may then only reappear in another cycle in another place, and at a higher stress.

Of particular interest is the evidence that the time of application of stress is an important factor in fixing the value of stress at which discharge appears; for example in the thin-wall cable specimens, the stress was taken up to 700 volts per mil without immediate evidence of discharge. Moreover at this high value of stress a considerable time was required before internal discharge appeared.

The tests on oil channels indicate that for short times the strength of these channels is quite high and probably very close to that of the oil alone. The lower values reported by Whitehead show the influence of time due perhaps, as suggested by him, to contact with the paper. The peculiar results found in the observation on air bubbles may perhaps be due to temperature, to saturation conditions in the gas, or to subsequent changes in volume or pressure in the gas. Further study is in progress, notably as to the time element, both under stress, and after its removal.

Table I

Frequency (Kilocycles)	Loss or Gain* (Decibels)				Amplification Factor
	Amplifier	Transformer	Filter	Total	
1	+74.0	− 3.4	−30.0	+40.6	107
2	+74.0	− 3.4	−20.0	+50.6	338
3	+74.0	− 3.4	−15.0	+55.6	600
4	+73.8	− 3.4	− 8.0	+62.4	1,300
5	+73.8	− 3.4	− 4.2	+66.2	2,040
7	+73.5	− 4.2	− 2.3	+67.0	2,240
10	+73.3	− 8.0	0	+65.3	1,830
15	+72.2	−11.3	− 1.4	+59.5	930
20	+70.8	−12.0	− 3.0	+55.8	620
30	+69.3	− 9.6	− 4.0	+55.7	606
40	+67.2	− 7.6	− 4.6	+55.0	561
50	+66.0	− 7.6	− 5.0	+53.4	470

*+ indicates a gain; − indicates a loss.

Conclusions

(1). Internal discharges occur in impregnated-paper insulation well in advance of failure and once initiated continue at stresses much below the breakdown values commonly attributed to this type of insulation.

The stresses at which initial discharges begin in insulation originally free of gas bubbles are from seven to eight times as high as the stresses usually obtaining in power cables.

(2). An improved method for detecting initial internal discharges in insulating materials is described. Calibrated in terms of gaseous ionization in thin air films of different thicknesses and at different pressures, it is found to detect initial discharge and its variation in accordance with Paschen's law.

(3). The seat of incipient failure in the samples of impregnated-paper insulation here studied is the oil channel between successive turns of paper tape. An initial discharge is followed by the evolution of gas which is ionized on successive alternating wave crests; the resulting oscillations are utilized for detecting the initial discharge and as a measure of the subsequent volume of discharge.

(4). Specimens stressed to the point where initial discharge begins may be brought back to apparently normal condition by allowing them to stand without stress for a period of time. This is attributed to the absorption of gas by the oil.

(5). A plus or minus variation with time under stress below the critical value, may occur in the volume of internal discharge. This is attributed to changes in pressure, or in volume of ionized gas, or to the absorption of gas by the oil.

Bibliography

1. The Dielectric Strength and Life of Impregnated-Paper Insulation, Part I, J. B. Whitehead. AIEE Transactions, volume 59, 1940, pages 715–20.

2. An Oscillograph Study of Corona, Edward Bennett. AIEE Transactions, volume 32, 1913, page 1787.

3. Bulletin No. 260, J. T. Tykociner, H. A. Brown, and E. B. Paine. Engineering Experiment Station, University of Illinois, 1933, page 6.

4. The Measurement of Discharges in Dielectrics, A. N. Arman and A. T. Starr. *Journal* IEE, volume 79, July 1936, page 67.

5. Influence of Residual Air and Moisture in Impregnated-Paper Insulation, J. B. Whitehead and F. Hamburger. AIEE Transactions, volume 47, 1928, page 314.

6. The Dielectric Strength of Air Films Entrapped in Solid Insulation and a Practical Application of the Problem for Alternator Coils and Cables, F. Dubsky. AIEE Transactions, volume 38, 1919, pages 537–58.

A Construction Theorem for Evaluating Operational Expressions Having a Finite Number of Different Roots

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IN the course of the past 25 years Heaviside's direct operational method of solving differential equations has, to a large extent, been replaced by solutions involving functional transformations. While mathematically sound this trend has resulted in placing a powerful analytical tool far above the mathematical equipment of the average engineer. With the exception of the celebrated expansion theorem or the method of partial fractions no *direct* method appears to have been discovered by which the average engineer or engineering student could solve even relatively simple differential equations by Heaviside's calculus. Several expansion theorems have been developed[1,2,3,4] to cover cases where repeated roots are present but none of these have been set up in a form which could be used by undergraduates. It does not appear that any direct general procedure has ever been suggested to cover the usual type of asymptotic solutions which appear in problems in electrical engineering.

It is the purpose of this paper to develop a direct method for evaluating operational expressions involving a finite number of different roots. For rational expressions the theory is based upon the usual procedure in obtaining the particular integrals of ordinary differential equations with constant coefficients. The procedure is heuristically extended to irrational operators by analogy so that its greatest utility lies in the field of asymptotic solutions.

The term "construction" has been applied to this theorem because the operations to be performed are only indicated as contrasted with the general solutions which characterize the "expansion type" theorems.

In order that this paper may be of value to engineers who are not familiar with integration in the complex plane no mathematically rigorous proof will be given. An outline for such a proof is presented in the last section.

Definitions and Fundamental Operations

Consider the steps necessary in solving for the particular integral of an ordinary linear differential equation with constant coefficients. As an example take the equation

$$(D+a)i = \epsilon^{bt} \tag{1}$$

where D is defined as the usual derivative operator of differential equations d/dt and t is the independent variable time. i is the dependent variable and is usually the current in amperes for electrical work. a and b are constants and $b > -a$. To solve for the steady-state current, or particular integral, divide both sides of the equation by $(D+a)$

$$i_s = \frac{1}{(D+a)}\epsilon^{bt} \tag{2}$$

The exponential can now be "shifted" from right to left.

$$i_s = \epsilon^{bt}\frac{1}{(D+a+b)}\,t \tag{3}$$

The next step is to expand the denominator in ascending powers of D by division or by the binomial theorem

$$i_s = \frac{\epsilon^{bt}}{a+b}\left(1 - \frac{D}{(a+b)} + \frac{D^2}{(a+b)^2} \cdots\right)t \tag{4}$$

Performing the operations indicated

$$i_s = \frac{\epsilon^{bt}}{a+b}\left(t - \frac{1}{a+b}\right) \tag{5}$$

which is the steady-state solution for equation 1. Notice that no arbitrary constants appear and that the process involves differentiation but no integration. This is important since the usual Heaviside operator p can be substituted in place of D. $1/p$ is to mean $\int_0^t dt$. In order to identify this general process a new operator will be defined.

Definition of a Bar Operator: Two bars placed over an operator $(p+a)^n$ are to indicate the complete operation of expanding the operator in ascending powers of p by the binomial theorem and performing the indicated differentiations. n may be a positive or negative real number including fractions. If this operator operates on a linear combination of powers of t multiplied by an exponential the first operation is always a "shift" of the exponential.

By the use of the bar operator the result shown in equation 5 can be expressed as

$$i_s = \overline{(p+a)}^{-1}\epsilon^{bt}t \tag{6}$$

Notice that equation 6 without the double bar might be confused with the equivalent complete operational solution which would include a transient term not indicated by (6).

These bar operators have several properties which are of interest when used with the fundamental and well-known operational expression

$$\frac{p}{(p+a)^n}1 = \frac{\epsilon^{-at}t^{n-1}}{\Gamma(n)} \tag{7}$$

n may be a positive integer, proper or improper fraction and a is a constant, real or complex. These properties are easily proved so that no proof will be given here.

1. Bar operators are commutative. That is, they may be used in any order to bring about the same result.

$$\overline{(p+b)}^m\overline{(p+c)}^r\left[\frac{\epsilon^{-at}}{\Gamma(n)}t^{n-1}\right] = \overline{(p+c)}^r\overline{(p+b)}^m\left[\frac{\epsilon^{-at}}{\Gamma(n)}t^{n-1}\right] \tag{8}$$

Where $a \neq b \neq c$ and r and m are positive.

2. Reciprocal bar operators perform reciprocal operations.

$$\overline{(p+b)}^m\left[\overline{(p+b)}^{-m}\frac{\epsilon^{-at}}{\Gamma(n)}t^{n-1}\right] = \frac{\epsilon^{-at}}{\Gamma(n)}t^{n-1} \tag{9}$$

3. In the case of "equal roots"

$$\overline{(p+a)}^m\left[\frac{\epsilon^{-at}}{\Gamma(n)}t^{n-1}\right] = \frac{\epsilon^{-at}t^{n-m-1}}{\Gamma(n-m)} \tag{10}$$

m and n are both positive integers or fractions. If $(n-m)$ is a negative integer or zero the gamma function of this number is infinite and the result is zero.

4. The case of unequal roots

$$\overline{(p+b)}^m\left[\frac{\epsilon^{-at}}{\Gamma(n)}t^{n-1}\right] = \epsilon^{-at}(b-a)^m\overline{\left(1+\frac{p}{b-a}\right)}^m\frac{t^{n-1}}{\Gamma(n)} \tag{11}$$

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1. For all numbered references, see list at end of paper.

n is positive but m may be positive, negative, or a fraction. $a \neq b$.

5. If $b=0$ and $n=1$ in case 4 the result is

$$\overline{(p)^m}\epsilon^{-at} = (-a)^m \epsilon^{-at} \tag{12}$$

For integral positive powers of m the bar operator behaves as an ordinary differential operator. If m is a fraction or has a negative value, however, the results are not the same as for the equivalent operational procedure. Purely imaginary terms obtained in this way must be set equal to zero after the final result has been obtained.

Since the bar operators behave in exactly the same manner for fractional values of n as for integral values a "fractional power" differential equation may be set up as easily as an "integral power" differential equation. As an example

$$\overline{(p+a)^{1/2}}i = \epsilon^{bt} \tag{13}$$

and the steady-state solution is, as in equation 6

$$i_s = \overline{(p+a)}^{-1/2}\epsilon^{bt} \tag{14}$$

It should be pointed out that these "fractional power" differential equations have been set up by analogy with "integral power" differential equations; a purely formal procedure.

Operational Differential Equations

An operational differential equation is to be defined for use in this paper as any one of the equivalent "fractional" or integral power differential equations which may be set up from an operational expression such as

$$i = \frac{p}{(p+a_1)^{n_1}(p+a_2)^{n_2}(p+a_3)^{n_3}\ldots(p+a_k)^{n_k}}1 \tag{15}$$

No loss in generality will result in the following theory if only three roots are considered since the process may obviously be extended to cover any number of roots. Consider the operational expression

$$i = \frac{p}{(p+a_1)^{n_1}(p+a_2)^{n_2}(p+a_3)^{n_3}}1 \tag{16}$$

Using the operator in the numerator in turn with each of the root functions in the denominator to form an expression corresponding to equation 7 the three most easily recognizable operational differential equations are

$$\overline{(p+a_2)^{n_2}(p+a_3)^{n_3}}i = \frac{\epsilon^{-a_1 t}t^{n_1-1}}{\Gamma(n_1)} \tag{17a}$$

$$\overline{(p+a_1)^{n_1}(p+a_3)^{n_3}}i = \frac{\epsilon^{-a_2 t}t^{n_2-1}}{\Gamma(n_2)} \tag{17b}$$

$$\overline{(p+a_1)^{n_1}(p+a_2)^{n_2}}i = \frac{\epsilon^{-a_3 t}t^{n_3-1}}{\Gamma(n_3)} \tag{17c}$$

The only restrictions are that $a_1 \neq a_2 \neq a_3$ and n_1, n_2, and n_3 are positive integers, proper or improper fractions. Notice that if the n's are positive integers the bars could be removed from the bar operators on the left-hand sides of equations 17 since they would then be ordinary differential equations any one of which could be represented operationally by (16).

It is now to be proved that in the case of integral positive values of n the unique solution for equations 17 consists of the sum of the particular integrals of (17a), (17b), and (17c). Actually these operations may be extended to fractional values of n but the proof to be given here is not mathematically rigorous. In this case the result usually includes an asymptotic series.

The following expression for $i(t)$ will satisfy equations 17.

$$i = \frac{1}{(p+a_2)^{n_2}(p+a_3)^{n_3}}\frac{\epsilon^{-a_1 t}t^{n_1-1}}{\Gamma(n_1)} + \frac{1}{(p+a_1)^{n_1}(p+a_3)^{n_3}}\frac{\epsilon^{-a_2 t}t^{n_2-1}}{\Gamma(n_2)} + \frac{1}{(p+a_1)^{n_1}(p+a_2)^{n_2}}\frac{\epsilon^{-a_3 t}t^{n_3-1}}{\Gamma(n_3)} \tag{18}$$

since when (18) is substituted back into, say (17a)

$$\overline{(p+a_2)^{n_2}(p+a_3)^{n_3}}\times\left[\frac{1}{(p+a_1)^{n_1}(p+a_2)^{n_2}}\frac{\epsilon^{-a_1 t}t^{n_1-1}}{\Gamma(n_1)}\right] + \overline{(p+a_2)^{n_2}(p+a_3)^{n_3}}\times\left[\frac{1}{(p+a_1)^{n_1}(p+a_2)^{n_2}}\frac{\epsilon^{-a_2 t}t^{n_2-1}}{\Gamma(n_2)}\right] + \overline{(p+a_2)^{n_2}(p+a_3)^{n_3}}\times\left[\frac{1}{(p+a_1)^{n_1}(p+a_2)^{n_2}}\frac{\epsilon^{-a_3 t}t^{n_3-1}}{\Gamma(n_3)}\right] = \frac{\epsilon^{-a_1 t}t^{n_1-1}}{\Gamma(n_1)} \tag{19}$$

The first term of (19) gives the same time function by (9) while the next two terms become zero since they involve expressions having "equal roots" as in (10). Equivalent results are obtained if (18) is substituted in equations 17b and 17c. That is, the solution (18) satisfies each of the operational differential equations 17a, 17b, and 17c. In terms of ordinary differential equation theory the first unit of (18) is the particular integral of (17a) and the second and third units together form the complementary function with constants of integration already evaluated. Thus the particular integral of one of the equations 17 forms a part of the complementary function for each of the other equations. Since the three original equations are known to have identical operational solutions equation 18 is always a unique evaluation of the operational expression (16). If the n's are positive integers the result (18) is always in a closed form. If (18) is extended to fractional values of n the result usually contains one or more asymptotic series.

The Construction Theorem

The process outlined in the last section can obviously be extended to cover any expression of the form (15) so that the equivalent time function would be given by:

$$i = \sum_{i=1}^{k}\frac{1}{\prod_{\substack{j=1\\ j\neq i}}^{k}(p+a_j)^{n_j}}\frac{\epsilon^{-a_i t}t^{n_i-1}}{\Gamma(n_i)} \tag{20}$$

The denominator of the bar operator of (20) is the same as that of (15) except that $(p+a_i)^{n_i}$ is omitted.

If the original operational expression (15) had a constant in the numerator instead of the operator p equation 20 would represent the solution for $pi(t)$. The final solution for $i(t)$ could be easily obtained, except in the case where (20) represents an asymptotic series, by operating on the result with p^{-1}. If the original expression had a numerator $F(p)$ consisting of a polynomial in integral powers of p equation 20 could be operated on with $F(p)$ to give the new solution. The integration must be performed before the differentiations or the net result of dividing $F(p)$ by p applied to equation 20.

The result may be given in the form of a "construction theorem" to evaluate operational expressions.

$$\frac{F(p)}{\prod_{i=1}^{k}(p+a_i)^{n_i}}1 = \frac{F(p)}{p}\times\left[\sum_{i=1}^{k}\frac{1}{\prod_{\substack{j=1\\ j\neq i}}^{k}(p+a_j)^{n_j}}\frac{\epsilon^{-a_i t}t^{n_i-1}}{\Gamma(n_i)}\right] \tag{21}$$

The restrictions for using this theorem are:

1. Functions having equal roots must be combined so that no two roots are identical including zero. The roots may be real or complex. (Two roots which are the same except for the sign are different roots.)

2. $F(p)$ is a polynomial containing only constants or constants multiplied by integral positive powers of p. In cases where the network is impulsive $F(p)$ will contain higher powers of p than the denominator. The result will not, in general, contain the impulsive terms which may be obtained in the usual manner.[8]

3. n_i is a positive integer, positive or negative proper or improper fraction.

4. In cases where the final result contains purely imaginary terms (as, for instance, in the case of $\sqrt{p}\epsilon^{-at}=\sqrt{-a}\epsilon^{-at}$ it is necessary to specify that such terms be dropped after all operations have been performed.

5. The theorem cannot be used in this from when $F(p)/p$ would operate on such terms as t^m where $m \leqq -1$. This restriction is necessary to prevent the "integration" of an asymptotic series.

The construction theorem in this form is more useful than the more complete form to be given which removes the last restriction. An operational expression which contains a fractional power root function in the numerator can usually be cleared of such terms by the usual algebraic procedure.

The last restriction may be removed by writing the left-hand side of equation 21 so as to segregate the zero root function. If $a_k=0$ and $n_k=q$ then

$$\frac{F(p)}{p^q\prod_{i=1}^{k-1}(p+a_i)^{n_i}}\mathbf{1}=$$

$$F(p)\left[\frac{p}{p^{q+1}\prod_{i=1}^{k-1}(p+a_i)^{n_i}}\right]\mathbf{1}=$$

$$F(p)\left\{\sum_{i=1}^{k-1}\frac{1}{p^{q+1}\prod_{j=1\ j\neq i}^{k-1}(p+a_j)^{n_j}}\frac{\epsilon^{-a_it}t^{n_i-1}}{\Gamma(n_i)}+\frac{1}{\prod_{i=1}^{k-1}(p+a_i)^{n_i}}\frac{t^q}{\Gamma(q+1)}\right\} \quad (22)$$

q is a positive integer or fraction. In this case $a_i \neq 0$. Multiplying both numerator and denominator by p arranges the expression inside the square brackets in the form of equation 15 so that the solution is given by the last line which is equivalent to equation 21. This final form of the construction theorem appears to be perfectly general under the limitations imposed by the first four restrictions. Only differentiations are involved which may be performed on any time function which may appear.

Illustrative Example

Evaluate the operational expression

$$i=\frac{p+c}{(p+a)(p+b)}\mathbf{1} \quad (23)$$

Using the first form of the construction theorem (21) $F(p)=p+c$ and (23) can be written

$$i=\left[\frac{p+c}{p}\right]\left[\frac{p}{(p+a)(p+b)}\mathbf{1}\right] \quad (24a)$$

Two of the fundamental forms (7) may be recognized in (24a)

$$i=\left[1+\frac{c}{p}\right]\left[\frac{1}{(p+b)}\left\{\frac{p}{(p+a)}\mathbf{1}\right\}+\frac{1}{(p+a)}\left\{\frac{p}{(p+b)}\mathbf{1}\right\}\right] \quad (24b)$$

From (7)

$$\frac{p}{(p+a)}\mathbf{1}=\epsilon^{-at}$$

and

$$\frac{p}{(p+b)}\mathbf{1}=\epsilon^{-bt}$$

and (24b) becomes

$$i=\left[1+\frac{c}{p}\right]\left[\frac{1}{(p+b)}\epsilon^{-at}+\frac{1}{(p+a)}\epsilon^{-bt}\right] \quad (24c)$$

Shifting the exponentials

$$i=\left[1+\frac{c}{p}\right]\left[\epsilon^{-at}\frac{1}{b-a}+\epsilon^{-bt}\frac{1}{a-b}\right] \quad (24d)$$

Performing the integration and rearranging the final result is

$$i=\frac{c}{ab}+\frac{1}{b-a}\left[\left(\frac{a-c}{a}\right)\epsilon^{-at}+\left(\frac{c-b}{b}\right)\epsilon^{-bt}\right] \quad (24e)$$

Cable With Terminal Inductance

One of the interesting problems originally solved by Heaviside[6] is the case of a unit voltage applied to an infinite cable with terminal inductance. The operational expression giving the voltage at the head end of the cable is of the form

$$V_0=\frac{1}{1+(bp)^{3/2}}\mathbf{1} \quad (25)$$

where b is a positive constant. Write this as

$$V_0=\frac{1-(bp)^{3/2}}{1-(bp)^3}\mathbf{1}$$

$$=\frac{1}{b^3}\left\{b^{3/2}p\times\left[\frac{p}{\sqrt{p}\left(p-\frac{1}{b}\right)\left(p+\frac{1-j\sqrt{3}}{2b}\right)\left(p+\frac{1+j\sqrt{3}}{2b}\right)}\right]-\frac{1}{p}\times\left[\frac{p}{\left(p-\frac{1}{b}\right)\left(p+\frac{1-j\sqrt{3}}{2b}\right)\left(p+\frac{1+j\sqrt{3}}{2b}\right)}\right]\right\}\mathbf{1} \quad (26)$$

The construction theorem may now be used for both terms.

$$V_0=b^{3/2}\left[\frac{p}{\sqrt{p}\left(p-\frac{1}{b}\right)\left(p+\frac{1-j\sqrt{3}}{2b}\right)}\times\epsilon^{-\left(\frac{1+j\sqrt{3}}{2b}\right)t}+\frac{p}{\sqrt{p}\left(p-\frac{1}{b}\right)\left(p+\frac{1+j\sqrt{3}}{2b}\right)}\epsilon^{-\left(\frac{1-j\sqrt{3}}{2b}\right)t}+\frac{p}{\sqrt{p}\left(p+\frac{1+j\sqrt{3}}{2b}\right)\left(p+\frac{1-j\sqrt{3}}{2b}\right)}\epsilon^{\frac{1}{2b}t}\right]-\frac{b^{3/2}}{1-(bp)^3}\left\{-\frac{1}{2\sqrt{\pi}}t^{-3/2}\right\}-\frac{1}{b^3p}\left[\frac{1}{\left(p-\frac{1}{b}\right)\left(p+\frac{1-j\sqrt{3}}{2b}\right)}\epsilon^{-\left(\frac{1+j\sqrt{3}}{2b}\right)t}+\frac{1}{\left(p-\frac{1}{b}\right)\left(p+\frac{1+j\sqrt{3}}{2b}\right)}\epsilon^{-\left(\frac{1-j\sqrt{3}}{2b}\right)t}+\frac{1}{\left(p+\frac{1+j\sqrt{3}}{2b}\right)\left(p+\frac{1-j\sqrt{3}}{2b}\right)}\epsilon^{\frac{1}{2b}t}\right] \quad (27)$$

When the indicated operations of (27) are carried through and the terms collected

$$V_0=1-\frac{4}{3}\epsilon^{-\frac{1}{2b}t}\cos\frac{\sqrt{3}t}{2b}+\frac{1}{2\sqrt{\pi}}\left(\frac{b}{t}\right)^{3/2}\times\left[1-1\cdot3\cdot5\cdot7\left(\frac{b}{2t}\right)^3+1\cdot3\cdot5\cdot7\cdot9\cdot11\cdot13\left(\frac{b}{2t}\right)^6\cdots\cdots\right] \quad (28)$$

The final result[8] as given by equation 28 checks that of Heaviside obtained by "advanced ideas" not stated.

This example is sometimes given as a case in which "Heaviside's method" fails, although he obtained the correct solution. As Heaviside himself made no general statement of his methods it might be inferred that he was at least partially aware of the relationship between his own work and ordinary differential equations. He makes the statement that,[7] "sometimes a series of differentiations may equivalently replace a series of integrations." It is unfortunate that he did not develop this relationship more fully.

Sinusoidal Electromotive Force Applied to an Infinite Cable

Another well-known problem is to find the entering current when a sinusoidal electromotive force is applied to an infinite cable. The operational equation is of the form

$$i=\sqrt{p}\sin\omega t\mathbf{1} \quad (29)$$

which is a combination of

$$\sqrt{p}\,1 = \frac{1}{\sqrt{\pi t}}$$

and

$$\frac{\omega p}{p^2+\omega^2}1 = \sin \omega t$$

Using the construction theorem

$$i = \omega p\left[\frac{1}{\sqrt{p}\,(p-j\omega)}e^{-j\omega t} + \frac{1}{\sqrt{p}\,(p+j\omega)}e^{-j\omega t} + \frac{1}{\omega^2+p^2}\frac{1}{\sqrt{\pi t}}\right] \quad (30)$$

and the final result is:

$$i = \sqrt{\frac{\omega}{2}}(\sin \omega t + \cos \omega t) - \frac{1}{\sqrt{\pi t}}\left(\frac{1}{(2\omega t)} - \frac{1\cdot 3\cdot 5}{(2\omega t)^3} + \frac{1\cdot 3\cdot 5\cdot 7\cdot 9}{(2\omega t)^5} \cdots\right) \quad (31)$$

One of the advantages of using this method of attack on operational expressions is the ease of checking the result obtained. Equation 29 may be set up in two equivalent operational differential equations:

$$(p^2+\omega^2)i = \frac{\omega p^3}{\sqrt{p}}1 = -\frac{\omega}{2\sqrt{\pi}}t^{-3/2} \quad (32)$$

and

$$\sqrt{p}\,i = \frac{\omega p^3}{p^2+\omega^2}1 = \omega \cos \omega t \quad (33)$$

If (31) is substituted in (32) the first term of (31) becomes zero since the second derivative of this term is the term itself multiplied by $-\omega^2$. All of the series terms will cancel out except the term on the right of (32). If (31) is substituted in (33) the first term of (31) becomes $\omega \cos \omega t$ and the odd-half power terms of (31) are reduced to zero as in equation 10.

Conclusions

The construction theorem which has been developed is not always the most direct method of solving every operational expression for which it is applicable. In the case of fractional power root functions the result will, in general, contain one or more asymptotic series. In particular if a certain solution is desired in terms of a convergent series of fractional powers of the variable t the result must be obtained by some other method. Several of the more obvious advantages in using the theorem may be listed as follows:

(*a*). The theorem brings out the relationship between ordinary differential equations and Heaviside's calculus. This results in the concept of "equivalent operational differential equations" which is far more important than the development of a fixed routine for the solution of individual operational expressions.

(*b*). The theorem involves no exceptions or complicated tests which must be applied before it is used.

(*c*). The necessary mathematical manipulations are easily learned since the main prerequisites are a knowledge of the binomial theorem and the ability to differentiate simple functions of time.

(*d*). Operational expressions which might otherwise be evaluated by Heaviside's expansion theorem can, more often than not, be evaluated by inspection.

(*e*). The final result may be easily checked by substituting results into the original equations.

Outline for a Rigorous Mathematical Proof of the Construction Theorem

To prove the construction theorem it is necessary and sufficient to show that the operations indicated by the key equation 18 can be substantiated by an equivalent procedure using the Bromwich[3] contour integral in the complex plane (*a*) for integral positive values of n and (*b*) for fractional positive values of n.

The symbols and definitions to be used in this discussion are given by reference 8.

Equation 16 becomes

$$i = \frac{1}{2\pi j}\int_{-j\infty+c}^{+j\infty+c} \times \frac{e^{zt}}{(z+a_1)^{n_1}(z+a_2)^{n_2}(z+a_3)^{n_3}}dz \quad (34)$$

1. Bromwich contour integral 1 is equivalent to Bromwich contour integral 2 for (34) since for large values of z the finite values of a may be set equal to zero and the proof is given by reference 8, pages 58–61.

2. The final result for (34) can now be obtained by taking the sum of the contributions of the individual roots along Bromwich integral 2. To evaluate the contribution of one root, say $-a_1$, first change the variable to $z' = z + a_1$. This is equivalent to the shifting operation indicated for $e^{-a_1 t}$ in equation 18. Expand the bracket terms containing a_2 and a_3 by the binomial theorem in ascending powers of z' separately and then perform the indicated multiplications. The resulting series is analytic for values of z' less than the least radius of convergence of the two original series but not for large values of z'.

The contribution of each root is now in the form of a series of terms of the type

$$\frac{e^{-a_1 t}}{2\pi j}\int_{Br_1}\frac{e^{z't}}{z'^{+1}}dz' = \frac{e^{-a_1 t}t^r}{\Gamma(1+r)} \quad (35)$$

good for all values of r. Proof for (35) is indicated on pages 76–8 of reference 8. Term by term this can be shown to be equivalent to the differentiating process indicated by the first unit of equation 18.

4. In the case of integral positive values of n the contribution of the two straight lines of Bromwich integral 2 for any particular root in an expression such as (34) is zero, so that (35) includes only the integral around the circle whose radius can be made as small as necessary to make the series expansion convergent. For integral powers of n equation 18 always gives the evaluation of expression 16 in closed form.

5. In the case of fractional powers of n the series expansions do not represent the original functions beyond the least radius of convergence of the two series. The expression to be integrated along the straight lines of Bromwich integral 2 does not converge except close to the new origin. However, for large values of t most of the integral is obtained in the neighborhood of the origin, a process which usually results in an asymptotic series.

In integrating along Bromwich integral 2 for fractional powers of n it sometimes happens that one root appears in the "tail" of the integration path for the other. In this case the weaker root may be dropped for an asymptotic solution. This is equivalent to the restriction 4 for the construction theorem. The contributions obtained in this way coincide with those given by the construction theorem.

References

1. Über eine Formel von Heaviside zur Berechnung von Einschaltvorgänge, **K. W. Wagner**. *Archiv. f. Elek.*, volume 4, 1916, pages 159–93.

2. The Cauchy-Heaviside Expansion Formula and the Boltzmann-Hopkinson Principle of Superposition, **F. D. Murnaghan**. American Mathematical Society Bulletin, volume 33, 1927, pages 81–9.

3. On a General Expansion Theorem for the Transient Oscillations of a Connected System, **John R. Carson**. *Physical Review*, volume 10, series 2 (1917), pages 217–25.

4. A Generalized Infinite Integral Theorem, **M. G. Malti**. AIEE Transactions, volume 54, 1935 (November section), pages 1222–7.

5. Operational Circuit Analysis (a book), **V. Bush**. John Wiley and Sons, 1937.

6. Electromagnetic Theory (a book), **Oliver Heaviside**. London, 1899, page 42.

7. Electromagnetic Theory (a book), **Oliver Heaviside**. London, 1899, page 303.

8. Complex Variable and Operational Calculus With Technical Applications (a book), **N. W. McLachlan**. Cambridge University Press, 1939.

A Study of Sound Levels of Transformers

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I. Introduction

MUCH has been accomplished in the past few years in understanding the problem of transformer noise. It has been definitely established that magnetostriction discovered by Joule in 1842 is the principal source of transformer noise. The various harmonic vibrations generated in the core by magnetostriction have been analyzed. Methods of calculating sound levels in terms of the standards prepared by the American Standards Association have been developed. A large number of modes in which different core structures may vibrate have been determined experimentally and analytically. As a result, methods for determining the correct design proportions of the core have been developed so that the natural modes of vibration may not coincide with the harmonic vibrations generated by magnetostriction. These methods have been successfully applied to actual designs of transformers including the largest ratings.

This paper will serve as a partial report of the research and experimental work which has been accomplished in the laboratories of the company with which the writer is associated.

II. Transformer Noise

Until recent years it had been assumed generally that the main cause of transformer noise was the magnetic pull between the laminations at their joints. In order to determine the correctness of this assumption, an investigation was started in 1932 by experimenting with an iron ring without gaps or joints. This ring was made up of laminations, 18 inches outside diameter, $8^1/_2$ inches inside diameter, built up to five inches. The laminations were clamped between heavy maple blocks; they could be energized by means of one turn through the center opening of the ring or more turns wound uniformly around the ring. When energized with alternating current, the ring emitted the characteristic "hum" heard from any transformer as soon as it is energized. The "hum" or noise increased as the flux density was increased. With a sine wave of voltage applied to the exciting winding and with a fixed number of ampere turns, the noise level was the same whether the ring was energized by means of one or several turns.

From these tests it was apparent that the joints in the core and mechanical dissymmetries between the energizing winding and the core could not account for the noise emitted from a well-built transformer.

In measuring the vibrations parallel with the plane of the laminations at different points around the periphery of the ring, it was found that the ring as a whole expanded with a very pronounced vibration of twice the applied frequency. These peripheral vibrations were all in phase or, in other words, the diameter of the ring was pulsating with an amplitude which was found to depend upon the flux density in the ring. It was only possible to explain these vibrations as a phenomenon of magnetostriction. The unit elongations calculated from these vibrations were of the expected order based on a knowledge of the magnetostriction.

Typical vibration measurements at the fundamental vibrational frequency taken on a rectangular core are shown in figure 1. It will be noticed that the deflections at the different flux densities are approximately proportional to the length of the various core members. The deflections shown occur simultaneously, that is, they are in phase. Vibrations as symmetrical as shown in figure 1[1] are obtained only when the laminations are straight and uniformly clamped. By changing the method of clamping, the deflections along a certain member may change considerably. The core may, for instance, vibrate as shown in figure 2.

The 120-cycle sound intensities calculated from the deflections shown in figures 1 and 2 correspond closely to those measured with a sound level meter with the microphone located approximately one-half inch from the core. The 120-cycle sound level of this core is, therefore, practically entirely accounted for by magnetostriction. The relation between magnetostriction and induction (B) is generally such that the core vibrates also at harmonically related higher frequencies. Both odd and even harmonic vibrations are produced. In figure 3 is shown such vibrations measured at one end of a large rectangular core. With the apparatus available, it was possible to measure vibrations up to the tenth harmonic. In this figure the vibrations are plotted as velocities. The amplitudes of the vibrations are in inverse ratio to the frequencies.

The number and magnitude of these higher harmonic vibrations depend upon the nature of the steel, the flux density, and the linear dimensions of the core. Any particular grade of steel has, therefore, a characteristic noise spectrum for each flux density. Such a spectrum is shown in figure 4 for steel at a flux density $B = 15{,}000$ gausses. The ordinates are plotted in decibels.

The core of any transformer is in itself a structure which may vibrate in many modes, depending upon its degree of freedom. When the laminations of a core as shown in figure 1 are clamped between heavy end frames, the core is practically free to swing only in a direction parallel with the plane of the laminations. A large number of modes of vibration are possible in this plane, each mode occurring at a certain frequency. This form of core and end frame construction is common in shell-type transformers. If the core is not clamped between heavy end frames and is standing upright as in core-type transformers, it has several degrees of freedom, that is, it may vibrate in several planes, and in numerous modes in each plane. In either case, it is possible that the core structure may be in mechanical resonance with one or more of the frequencies generated in the core due to magnetostriction. The amplitudes of vibration at such frequencies will, therefore, be in excess of the forced vibrations caused by magnetostriction.

In figure 5 are shown some typical vibration measurements made on a shell-type transformer which was energized at a constant induction at different frequencies. In this test the core was not clamped tight, and the bottom and top end frames were, therefore, more or less loosely coupled with the core. The vibrations were measured at five points along the vertical center line of the long side as shown.

The upper end frame showed resonance at approximately 100 cycles (figure 5, point 5a); above 130 cycles it was driven

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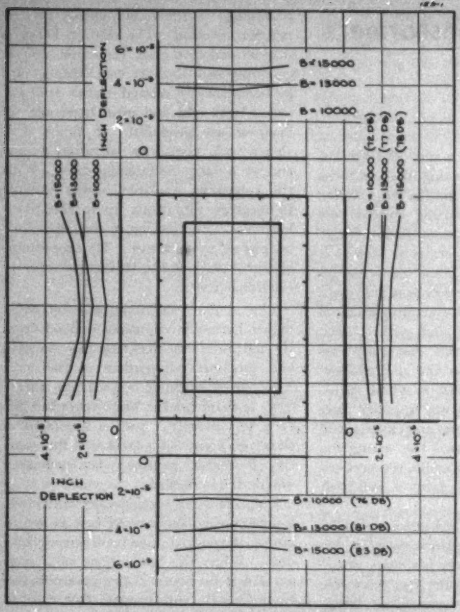


Figure 1. 120-cycle core deflections parallel with the plane of laminations at 60-cycle excitation

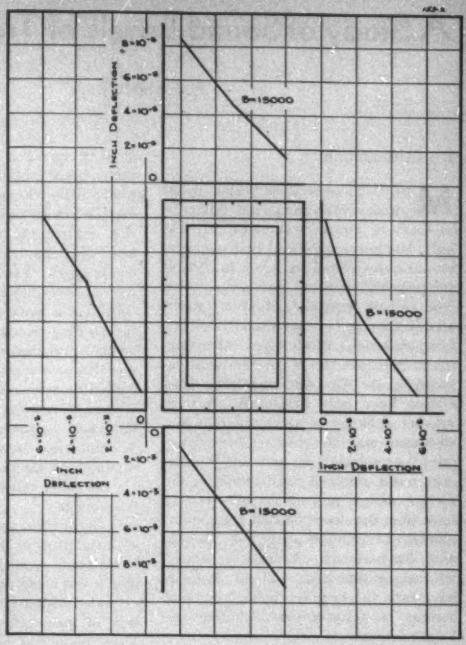


Figure 2. 120-cycle core deflections parallel with the plane of laminations at 60-cycle excitation

by the core which was in resonance at 136 cycles as shown in figure 5 (points 5*b*, 5*c*, and 5*d*). The calculated deflection of the core, due to magnetostriction, was approximately 0.05 mil double amplitude, and it will be noted that at 136 cycles, the core vibrated with an amplitude 16 times that corresponding to the magnetostriction. This means that the noise level on this side of the core was approximately 24 decibels higher than normal at this particular flux density. From figure 5, point 5*e*, it will be seen that the lower end frame is in resonance at approximately 102 cycles and starts to be driven by the core when the frequency was above 132 cycles.

By increasing the coupling between the core and the end frames, that is, by clamping the structures together, the vibrations in the range from 100 to 130 cycles will be somewhat increased. It is, therefore, evident that it is desirable that the core and the end frames have as nearly as possible the same natural frequencies. It will also be noted from these figures, that the band of partial resonance extends about 20 to 25 cycles on either side of the resonance frequency.

The mode of vibration at the resonance frequency of 136 cycles was determined by the use of two equally sensitive vibration pickups connected in series so that their voltages add. The mode was of the nature shown in figure 6*a*. Two of the opposite sides are deflecting outward at the instant the other two sides are deflecting inward. This is the lowest possible mode for a box structure which has practically only one degree of freedom. The exciting frequency of the supply at the 136 cycles vibrational frequency was 68 cycles. The same mode would have occurred at 136 cycles if the core had been energized at 34 cycles. In this case, the core would have been in resonance with the second harmonic vibration due to magnetostriction. But, because of clamping in the core and since for this particular steel the second harmonic driving force is less than for the fundamental, the amplitude of the 136-cycle vibration would have been less.

If the frequency had been further increased above 136 cycles, another resonance point would have occurred at approximately 292 cycles. The mode of vibration at this frequency would have been as shown in figure 6*b*. Here all four sides are simultaneously deflecting outward. This mode requires a rather rigid joint at the corners and is, therefore, not always excited.

At still higher frequencies more complicated modes are excited. The different sides will then vibrate in odd number of half cycles.

Figure 7 shows the consecutive modes of vibration which occur in a three-phase shell-type transformer.

The frequencies of these modes depend upon the dimensions of the core and the modulus of elasticity of the steel used. They may be calculated from a formula of the form

$$f = K\frac{W}{l_1^2} \qquad (1)$$

where

K = a function of the ratio l_1/l_2 and the modulus of elasticity
W = width of the laminations
l_1 = mean length of the longest side
l_2 = mean length of the short side

From experimental data it has been found advisable to design the core of

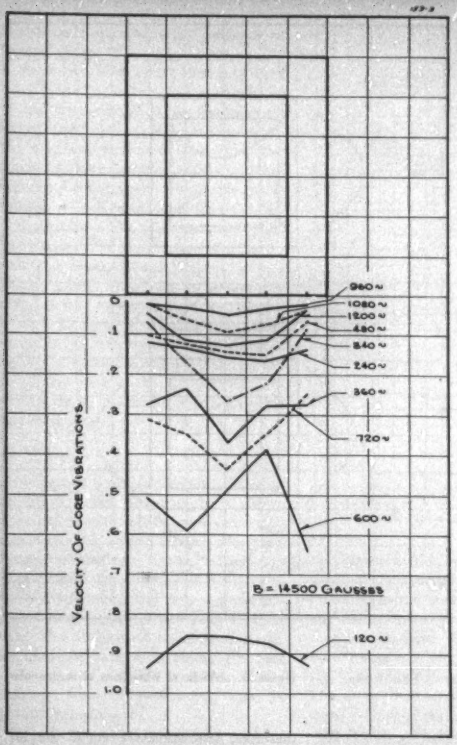


Figure 3. Velocity of core vibrations parallel with the plane of laminations at 60-cycle excitation

such dimensions that its natural frequencies are separated approximately 25 to 30 cycles from any of the harmonic frequencies generated in the core by the excitation frequency.

The end frames for shell-type transformers are more or less complicated box structures and their natural frequencies may be determined along the same lines as indicated for the core.

As previously stated, the core-type transformer as usually constructed is free to vibrate in several planes. The modes of vibration parallel with the plane of the laminations may be of the same nature as the modes described for box structures, and may be determined by means of equation 1. Such a mode for a single-phase core-type transformer is shown in figure 8. In this particular core the mechanical resonance frequency was 294 cycles. This mode would, therefore, not be excited by any of the frequencies generated in the core at 60-cycle excitation. The amplitudes in the center of the legs are approximately 19 times that corresponding to the magnetostriction at this particular flux density. On the other hand, the upright core represents two or more columns with a load at their ends which are free to vibrate in planes principally parallel and perpendicular to the laminations. The core may, therefore, also vibrate in modes as shown in figures 9 and 10, in a plane parallel with the laminations or in modes as shown in figure 11, in a plane perpendicular to the plane of laminations. In figure 11, the elongations of the legs in the direction of their length are restrained by inertia forces due to the presence of large masses on their ends, and they bow out. Some of these modes are rather critical and difficult to duplicate under apparently similar conditions. They are apparently influenced by the mounting of the core on its foundation.

With resonance eliminated, by proper selection of the core dimensions, the amplitude (A) at the fundamental vibrational frequency of any member of the core may be calculated from the magnetostriction characteristics of the steel. For a core member of length (L), the amplitude at each end equals

$$A = \frac{\Delta L}{L} \times \frac{L}{2} \qquad (2)$$

where $\Delta L/L$ = elongation per unit length due to magnetostriction. The corresponding physical intensity of the sound wave may be calculated by means of the fundamental equation for a plane sound wave, emitted from a large plane vibrating surface.

The maximum excess pressure in such a wave equals

$$P = V \times d_0 \times A \times 2\pi f \qquad (3)$$

where V = velocity of wave, d_0 = mean density, A = maximum amplitude of the wave, and f = frequency.

When V is in centimeters per second

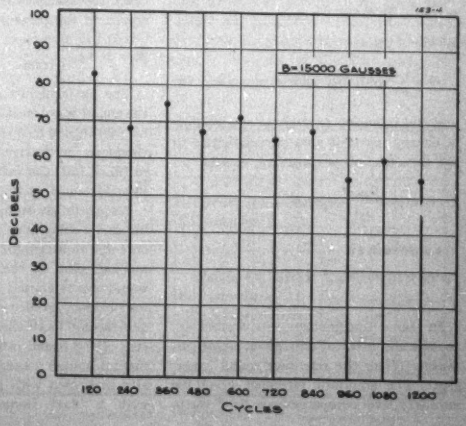


Figure 4. Noise spectrum of transformer steel at 60-cycle excitation

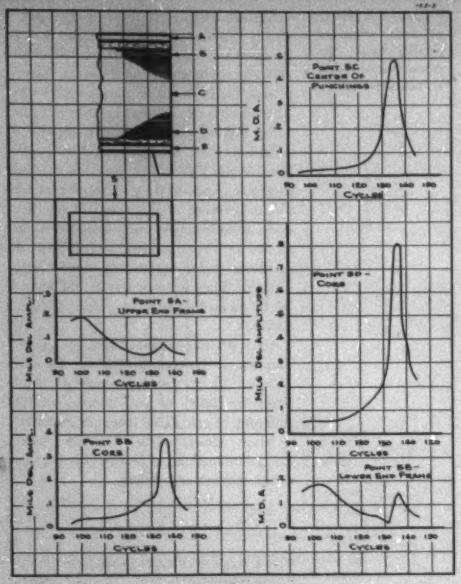


Figure 5. Resonance curve of shell-type transformer core. Core not clamped

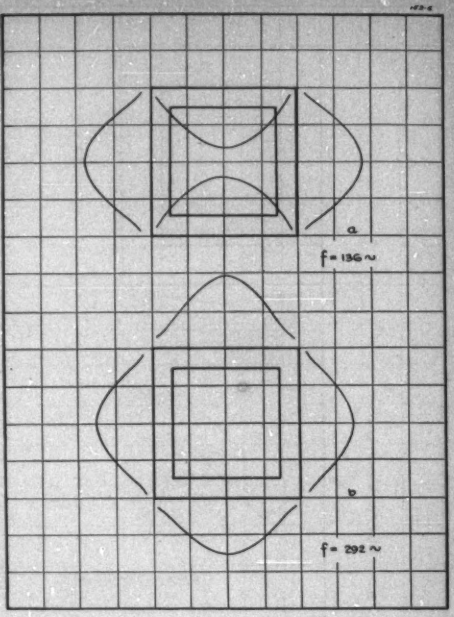


Figure 6. Mode of vibrations of rectangular cores

(=33,300 for air), d_0 in gram per cubic centimeter (=0.0012 for air), the rms excess sound pressure in dynes per square centimeter equals

$$P_{rms} = 177 \times A_{cm} \times f \tag{4}$$

or if A is in inches

$$P_{rms} = 452 \times A_{in} \times f \tag{5}$$

The average energy density of such an acoustic wave equals

$$W = 2\pi^2 A^2 f^2 d_0 = \frac{P_{rms}^2}{d_0 V^2} \text{ gram per cubic centimeter} \tag{6}$$

and the intensity or average rate of flow of energy per unit area perpendicular to the direction of propagation, equals

$$I = W \times V = \frac{P_{rms}^2}{d_0 V} \text{ ergs per second per square centimeter} \tag{7}$$

For a wave in air

$$I = 2.5 \times 10^{-9} \times P_{rms}^2 \text{ watts per square centimeter} \tag{8}$$

In sound terminology, the decibel expresses the ratio of any given sound intensity (I) to the reference sound intensity. The standard reference level for intensity level comparisons is 10^{-16} watts per square centimeter. The decibel is defined as

$$\text{db} = 10 \log_{10} \frac{I}{10^{-16}} \tag{9}$$

The decibel also expresses the ratio of any given sound level pressure (P) to the reference pressure. The standard reference level for pressure level comparisons is 0.0002 dyne per square centimeter. Since the intensity is proportional to the square of the pressure, we have

$$\text{db} = 20 \log_{10} \frac{P}{0.0002} \tag{10}$$

The physical intensity, in decibels, of the sound wave emitted at the fundamental vibrational frequency of the core may, therefore, be determined by substituting in (9) or (10) the values for I or P determined from (8) or (5).

As previously stated, a large number of harmonic vibrations are produced in the core due to magnetostriction. The arithmetical sum of the intensities, of the sound waves caused by these vibrations, for ordinary grades of silicon steel, is in general not more than one decibel in excess of the sound intensity of the fundamental sound wave. The sound intensity measured with a sound level meter with a "flat" frequency response will, therefore, approximately equal the intensity of the fundamental sound wave calculated as indicated above. This value will be designated as db_F. The intensities of the individual harmonics may also be weighted according to any of the recognized standard equal loudness contours for pure tones. For transformers it is the standard practice to refer all sound level measurements to the 40-decibel equal loudness contour. This value may be measured directly with a modern sound level meter, and will be designated as db_{40}.

The difference between the sound measured with the "flat" and the 40-decibel frequency response will give a fair indication of the quality or the harmonic components of the sound measured. This difference may, therefore, be designated "harmonic index" (h.i.), or

$$\text{h.i.} = \text{db}_F - \text{db}_{40} \tag{11}$$

Where the h.i. is large it is an indication that the sound contains large components of low-frequency tones, whereas a small h.i. indicates that higher frequency tones are predominating.

The harmonic index of a certain grade

of steel as a function of the induction is shown in figure 12.

The sound level of the core may now be estimated as follows. The amplitude of the core vibrations at fundamental vibrational frequency is determined from the magnetostriction of the steel, the length of the magnetic circuit involved, and the flux density at which the core is worked. From this amplitude the excess pressure of the sound wave in dynes per square centimeter and the corresponding decibel sound intensity is calculated (db_p). In order to obtain the sound level corresponding to the 40-decibel frequency response, the "harmonic index" corresponding to the flux density at which the core is worked should be subtracted from the above sound intensity, or the sound level of the core is approximately

$$db = db_p - h.i. \qquad (12)$$

Numerous tests on different cores and at different flux densities have shown close agreement between the calculated and measured sound levels. However, because of the large number of assumptions made in these calculations and since these assumptions are only approximations, caution should be made in their use. The method of calculation would, for instance, have to be changed in case the steel has a sound spectrum widely different from that commonly used in present transformers.

It is well known that the load currents give rise to magnetic forces around and between the high- and low-voltage coils of a transformer. These forces will produce vibrations of the coils with double the applied frequency. Higher harmonics are in general not produced. The construction of the coils is in general such that they are relatively poor sound radiators. In a properly designed transformer, the vibrations produced by the coils will, therefore, contribute relatively little to the total noise level of the transformer when measured on the 40-decibel frequency response.

When the core and coils are placed in their tank and immersed in oil, their motion is transmitted through the oil to the tank wall and from there emitted as sound waves to the surrounding air. For most of the vibrations generated in the core the oil may be considered an incompressible fluid. This means that the oil will act as an added mass to the tank wall and only a small amount of energy at the higher frequencies will be transmitted through the oil and the tank wall as a true wave motion. The tank wall, bottom, and cover are, therefore, forced to vibrate as diaphragms. In general, these diaphragmatic vibrations are not produced in the tank wall as a whole, at any frequency. The tank is a relatively complex structure. Radiators, potheads, switch cabinets, etc., may be welded to the tank wall. Its surface is, therefore, broken up in a large number of smaller areas, vibrating with different phases and magnitudes. Provided no parts of the tank surface are in resonance with any of the exciting frequencies produced by the core, the resulting vibrations are forced. Their magnitudes may be smaller than that of the core. The reduction depends upon the height and thickness of the tank wall, the distance between the core and tank wall, the relative density of the material of the tank wall and that of the oil.

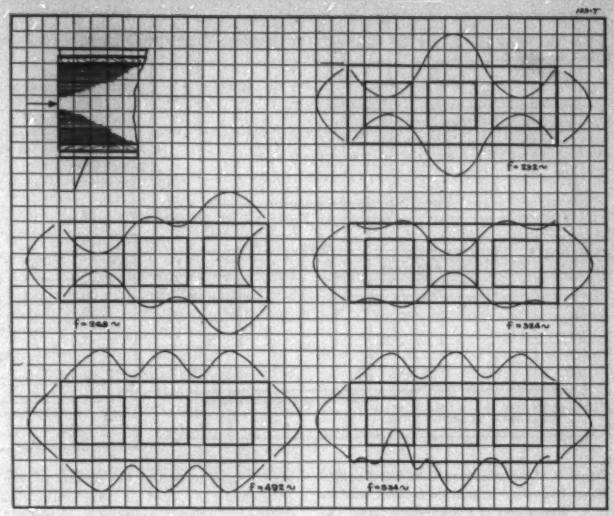


Figure 7. Phase relations of vibrations measured on center line of three-phase shell-type transformer

Methods for predetermining the amount of attenuation are being studied, but the problem is very complex and empirical constants are used at present.

Assuming the oil to act as an incompressible fluid, the average "harmonic index" of the tank wall vibrations will correspond closely to the average "harmonic index" observed on the core itself. For example, on one of the largest transformers built, the average "harmonic index" of the core was 9.1 decibels when measured out of its tank. When the transformer was placed in its tank, the average h.i. measured 9.6 decibels, indicating relatively little change in the harmonic vibrations of the core and the tank wall. A large number of similar

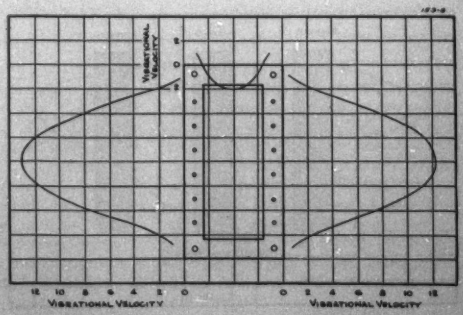


Figure 8. Magnitude and phase relations of 294-cycle vibrations parallel to the plane of laminations

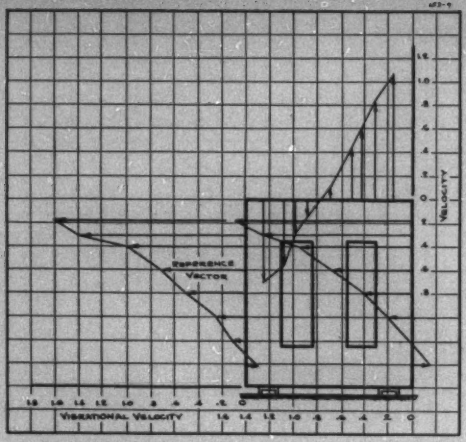


Figure 9. Core vibrations at 124-cycle vibrational frequency in a plane parallel with the laminations of a three-phase core

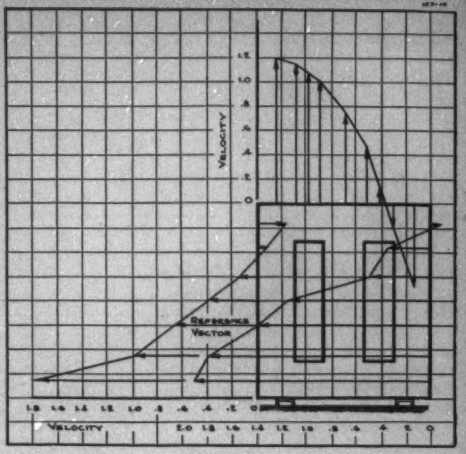


Figure 10. Core vibrations at 116-cycle vibrational frequency in a plane parallel with the laminations of a three-phase core

tests on a variety of transformers have given similar results. Where a large discrepancy has been observed it has been an indication of resonance in some parts of the tank wall or improper mounting of the transformer in its tank. The tank wall or segments of the tank wall may have free vibrations of their own at a large number of frequencies and modes. If such vibrations are in resonance with any of the core vibrations, they may in general be reduced by relatively simple means, such as braces anchored at suitable points.

Cooling tubes, radiators, etc., may complicate the motions of the tank wall, but in themselves these parts are relatively poor sound radiators for sounds of the frequencies involved in transformer operation. They contribute, therefore, relatively little to the total sound level of the transformer.

The vibrations of the tank may produce two kinds of sound, when the transformer is installed in its final location:

1. A direct air-borne sound, radiated from the tank wall, cover, radiators, etc.

2. A sound transmitted through the transformer foundation to the wall or other structural work of the building in or near where the transformer is installed.

Of these two sources, number 1 is, in general, the most important and also the most difficult to insulate against. Air-borne sounds must be "sealed in." This may be accomplished by means of sound-absorbing walls surrounding the transformer, but this is a remedy which seldom can be used.

Source number 2 may be of importance in certain installations where large areas may be set in vibration by transmission of vibrations through materials like steel or concrete which transmit vibrations much more readily than air. Such vibrations may be reduced by elastic support between the transformer base and

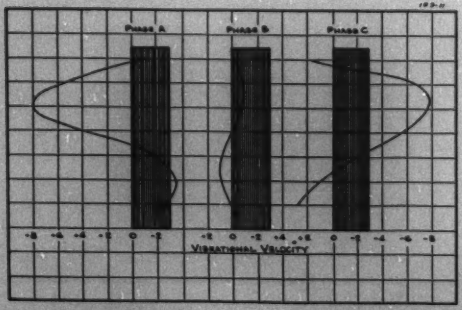
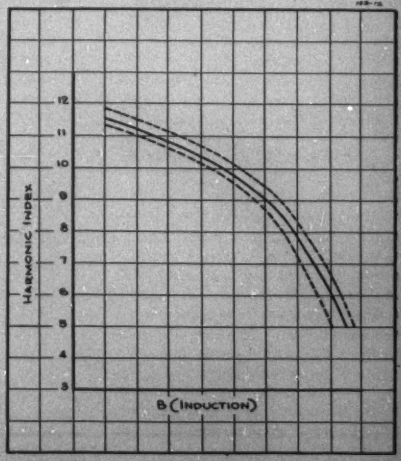


Figure 11. Phase relations of 116-cycle vibrations perpendicular to the plane of laminations of a three-phase core

Figure 12 (right). Harmonic index of transformer steel corresponding to 40-decibel frequency response



Suppression of Magnetic Vibration and Noise of Two-Pole Turbine Generators

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THE constant striving for improvement in over-all economy in the generation of electric power by steam has resulted in the last three or four years in a rather rapid increase in the capacity of steam turbine generators built to operate at 3,600 rpm. One of the factors contributing to this growth was the progress made in the use of high-pressure and high-temperature steam which led to the application of a number of such turbines for superposition on existing comparatively low-pressure steam plants, as well as for straight through condensing operation. The operating experience with such recently developed 3,600-rpm generators ranging in capacity up to 66,667 kva has been unusually good. The troubles which have been experienced, either mechanical or electrical, have not been of a serious nature.

While 3,600-rpm generators have been built for many years, the double-frequency vibration and noise produced by them was not until recent years of much moment or concern. The comparatively recent machines with which we are here concerned are large as compared to the earlier ones and have in many cases produced an objectionable amount of 120-cycle noise and vibration, the noise being often an intense humming of all-pervading character, seeming to go all through the plant. The intensity of the noise, at some points, is materially affected by reflection from various smooth surfaces, being particularly loud where the reflected sound wave reinforces the original.

In addition, the actual amplitude of the mechanical vibration has been sometimes sufficient to result in severe vibration of many parts of the station structure or equipment such as beams, brackets, floor plates, housings or parts of them, even exciter brush arm brackets, latch mechanisms, or perhaps delicate relay parts. This is particularly so if the natural period of vibration of some beam or part is in resonance or near resonance with the vibration source.

Early investigations of the 120-cycle vibration and noise showed that they resulted when field excitation was applied to the generator and that in fact they were two aspects of the same disturbance. This definitely indicated that the cause was magnetic. The disturbance, as has been pointed out in a previous paper,[1] is due to the magnetic forces of a two-pole field rotor bringing about a distortion of the stator into an elliptical shape, the distortion revolving in synchronism with the rotor. Since each pole of the rotor pulls the stator radially inward, any point on the stator core vibrates at a frequency double that of rotation, or at a frequency of 120 cycles for a 3,600-rpm machine.

As is well known, the magnetic force of attraction between the stator and rotor at any given point varies as the square of the flux density at that point. Figure 1 has been plotted in terms of magnetic force or pull as determined from the flux distribution typical of a two-pole machine.

While the magnetic vibration has not been severe enough to have any apparent effect on the life of the stator winding or other parts, nevertheless, the noise has in many instances been so intense as to be very annoying to live with, which indicated that there was a need for some means of suppression or mitigation of this noise and vibration and led to the undertaking of a careful analysis of the problem. The presentation of the various phases of this analysis, together with a description of the development of an apparently complete cure for the double-frequency magnetic vibration nuisance by means of a simple form of resilient core mounting, is the subject of this paper.

Observations on Magnetic Vibration

Since the double-frequency vibration and noise are caused by distortion of the generator stator structure, the amount of this distortion is of primary importance. The frequency being high, special equipment is required for accurate measurement. Readings of vibration amplitude taken with an optical amplitude indicator on a representative large two-pole machine of early design are shown in figure 2. These were taken radially on the surface of the stator, and the plot shows the variation in amplitude along the length of the machine. The same curve applies to either side or the top of the generator, or at any angle in between, for *radial* amplitudes. With excitation removed, this vibration disappears, although there is usually a residual vibration at running speed frequency, transmitted from the rotor, which is small if the machine is well balanced. The residual vibration in this case is shown by the dotted curve.

The variation of this double-frequency

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1. For all numbered references, see list at end of paper.

the foundation. This elastic support should be correctly designed, otherwise its effect may be very detrimental. The elastic support should have a natural frequency considerably below the lowest impressed vibrational frequency produced by the transformer. Spring supports are, in general, not practicable. There are on the market special high-grade rubber compounds which do not lose their resilience appreciably with time.

The problem of transformer sound and methods for its reduction is far from being solved. With the exception of reduction in magnetostriction, no means have been found by which the sound level may be economically reduced. Continued research is being done on this problem. The company with which the writer is associated has a large soundproof room which is used to facilitate such investigations. This room has inside dimensions of 24 feet by 25 feet and 22 feet height. It is of a double-room construction. The outer room is of eight-inch brick walls with a seven-inch thick concrete roof. The inner room is completely insulated from the outer room. Its walls and ceiling are constructed of sound-absorbing material particularly effective for frequencies in the range from 100 to 1,000 cycles. A seven-inch air space separates the two rooms. The average attenuation is of the order of 55 decibels, which is sufficient for the work for which the room was designed.

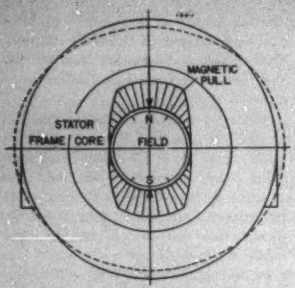

Figure 1. Magnetic pull of a typical two-pole a-c generator

amplitude with speed is shown in figure 3. It may be noted that, as speed is reduced below 3,600 rpm, with constant excitation, the amplitude drops off somewhat, but levels off to a definite value for zero speed. The shape of this curve is similar to part of a resonance curve, and suggests that if the speed could be carried considerably beyond 3,600 rpm, the amplitude would increase greatly, perhaps reaching a peak value at some higher speed.

Analytical Approach to Problem

Consideration of data such as are shown in these figures suggested an analytical approach to the problem to account for the observed vibration, along the following lines:

(1). Evaluation of the magnetic forces acting radially in the air gap between rotor and stator;

(2). Calculation of the deformation of the stator structure by these forces, considered as acting statically, that is, with the rotor at rest;

(3). Estimation of a resonance "build-up" factor (ratio of running amplitude to static deformation) based upon the relationship of the frequency of the magnetic forces at running speed to the natural frequency of the stator vibrating as a cylindrical ring with a four-node pattern.

Tests on Stiffness of Stator Elements

The magnetic forces were found to be rather large, equivalent roughly to two concentrated opposite radial loads on the stator of the order of 50,000 to 100,000 pounds each in large machines. The static deformation of the stator frame by such forces, assuming at first that the core laminations had no stiffness of their own, was calculated by well-known ring formulas[2,3] to be far greater than the observed vibration. It seemed therefore that the laminations must contribute a large share of the total stiffness of the stator. As a check on this point, deflection tests were made on a full-sized stator frame of greater than average stiffness before and after the laminations were assembled, with results as shown in figure 4. The frame was set on the factory floor and loaded with heavy rotor forgings laid on top of it on wooden chocks, and the deflection measured by means of dial indicators set to register the change in the vertical diameter. Upon removal of the loads, the indicators all returned to zero. It will be noted that with the heaviest load, the bare frame deflected 10.5 mils, as compared with 1.3 mils after assembly of the core.

In anticipation of these results, and to settle the question as to whether this great stiffness was a property of the tightly pressed core itself or depended upon assembly of the core in the frame,

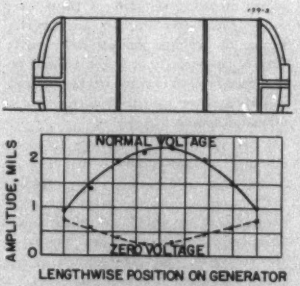

Figure 2. Distribution of vibration on stator of a two-pole generator

a ring had been made of some of these same laminations pressed together with rectangular steel bars as shown in figure 5. This ring was also subjected to deflection tests, by loading it across a diameter with a hydraulic jack, and measuring the deformation with dial indicators in much the same way as on the frame. It was found that this ring of punchings was quite elastic; that it would take loads up to several times the normal magnetic load, and return to its original shape; and that it was exceedingly stiff, sufficiently so to account fully for the difference in stiffness between the bare frame and the stacked frame. Also, while the ring stiffness varied somewhat with the tightness of clamping, this effect was comparatively slight so long as the laminations were reasonably tight. In short, the core was found to be a cylinder of great strength and stiffness independent of the generator frame.

Tests to Determine Natural Frequency of Core

Other rings of punchings were tested with similar results. Further tests were made on them to determine the natural frequency as a cylindrical ring vibrating radially with a four-node pattern. The two types of tests, for static stiffness and for natural frequency, were correlated, and it was found possible to calculate the natural frequency of a core structure with reasonable accuracy. In all cases, it was found to be high, of the order of 160 to 200 cycles in the largest machines, and higher in smaller machines.

Use of Resonance Curve in Calculating Magnetic Vibration

This information made it possible to carry through with the three steps suggested for the calculation of the amplitude of magnetic vibration of two-pole generators in general. The stiffness of the frame usually being small in comparison with that of the core, little error results from leaving the frame entirely out of the calculations. The first two steps, to determine the magnetic forces and the resulting static deflections of the cylindrical ring of punchings, are carried out by well-known methods that do not need to be repeated here. The third step makes use of a resonance curve such as that shown in figure 6. Here amplitude is plotted against the frequency of the deflecting force. For zero frequency, i.e., a steadily applied force, the amplitude is shown as 1.0, which represents the static deflection. With increasing frequency, the amplitude increases and reaches a peak value at resonance, when the frequency of the deflecting force equals the natural frequency

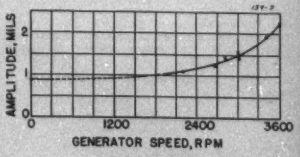

Figure 3. Variation of magnetic vibration with speed

of the setup. The frequency scale is also on a per-unit basis, with 1.0 representing resonance. For higher frequencies beyond resonance, the amplitude decreases rapidly. This relationship between amplitude and frequency is rigorous[4,5] for any simple system in which the disturbing force remains constant in magnitude

as the frequency varies. It has been assumed to apply to a cylindrical ring. Damping has been neglected; if taken into account it would reduce materially the amplitudes near resonance, as shown by a sample dotted curve. However, the four-node natural frequencies of the generator cores were found to be so far above the impressed frequency of 120 cycles that damping can be neglected. The use of the curve is fairly obvious. It merely shows a "build-up" factor, representing the increase of the running amplitude above the static deflection. For example, if the natural frequency of the stator core is determined as 200 cycles the ratio of impressed frequency to natural frequency is 120/200 or 0.6; and the "build-up" factor is 1.56.

Improvement Obtained by Increased Radial Depth of Core

Calculations were made along these lines for all large 3,600 rpm generators made by the General Electric Company. Agreement between the calculations and the maximum of test observations similar to those plotted in figure 2 was very satisfactory. It was obvious from the results that considerable reduction in the vibration could be obtained by the use of punchings of increased radial depth. The greater stiffness of such "deep core" machines helps in two ways: (1) it reduces the "static" deformation; and (2) it increases the natural frequency so that the "build-up" factor is also reduced. Deep-core construction has been used in quite a number of generators in the past two years, with a gratifying reduction in the double-frequency disturbance. The ratio of improvement in the largest machines has been of the order of two to one.

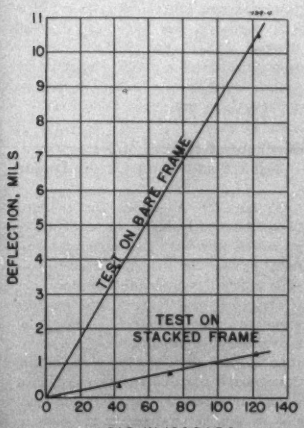

Figure 4. Results of deflection tests on stator frame

Consideration of Resilient Mounting of Core to Isolate Vibration

Although the improvement obtained by the simple expedient of deepening the core was considered to be sufficient to remove most of the nuisance effect of the noise and vibration in all cases where station acoustics are reasonably good and mechanical resonance is avoided in adjacent structures, nevertheless it seemed desirable to see what could be done to eliminate the magnetic disturbance almost entirely. A suggestion to this end had been made by L. P. Grobel, shortly after the first large 3,600-rpm generators came to test. His proposal was to isolate the vibration by mounting the core on spring members within the stator frame. This seemed like a rather radical departure, but the tests described in preceding paragraphs demonstrated that the tightly pressed laminated cores had great strength and stiffness of their own, and indicated that the isolation idea was an inviting possibility. A number of complications, however, had to be faced. First, should the spring members provide radial flexibility only, and be rigid tangentially; or should they be flexible both ways? Second, if the frame is not attached rigidly to the core, its own four-node natural frequency will determine its response to the stimulation coming through the spring members, and must be taken into account. Third, the core should apparently be mounted in such a way that it will not have natural frequencies for bodily motions which would cause it to respond unduly to the running speed frequency disturbances caused by unbalance of the rotor. Fourth, the core mounting must be designed to withstand the severe torsional effect of short circuits. A complete treatment of these matters is entirely beyond the scope of this paper. They will be briefly discussed, however, in the next few paragraphs.

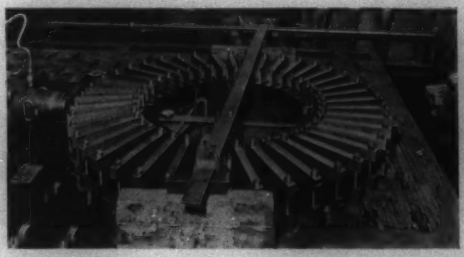

Figure 5. Setup for deflection tests on ring of core laminations

Tangential Displacements of Cylindrical Rings

A tangentially rigid but radially flexible type of mounting was suggested independently by several engineers within the General Electric Company, and was given serious consideration. Its effectiveness would apparently depend upon the amount of tangential vibration accompanying the radial vibration at the point of attachment, at the outside diameter of the core, or farther out if a double frame should be used. It is not at once obvious that there should be any tangential motion at all, although it was pointed out long ago by Lord Rayleigh[6] that in the case of a *thin* circular ring, elliptical distortion or four-node vibration resulted in a tangential displacement of the nodal points equal to just 50 per cent of the maximum radial displacement. This is illustrated in figure 7, from which the reason for the tangential displacement may be seen. The distance around a quadrant of the deflected ring, from one 45-degree point to the next, is obviously greater across the major axis than across the minor axis, so that, unless the ring is forcibly stretched in two quadrants and shortened in the other two, the "nodal" points at 45 degrees must move tangentially.

Two-pole generator cores, however, are not thin rings, but relatively deep ones. An investigation was made to determine how the tangential displacement might vary with the ring depth. The curves in figure 8 are drawn to illustrate some of the results of an analysis made by Doctor H. Poritsky and H. D. Snively. These show that deep rings have a tangential displacement of more

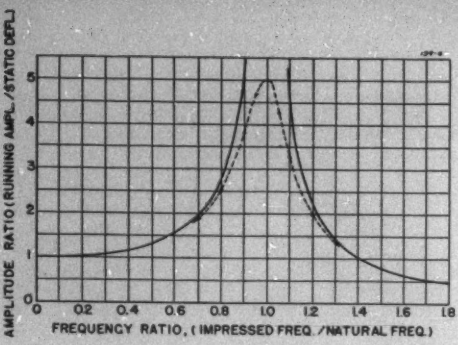

Figure 6. Basic resonance curve

than 50 per cent of the radial displacement, at the inside diameter; but less than 50 per cent at the outside. The exact values depend upon the depth ratio (outside diameter)/(inside diameter). Amplitude observations during the tests for the natural frequency of rings of punchings, described in a previous paragraph, gave an excellent check on these curves, as shown by the X points (figure 8). It seems that for two-pole generator cores of normal proportions, with a ratio of outside to inside diameter (over the slots) of 1.5 to 1.6, the tangential vibration on the outside diameter is likely to be about 20 per cent or more of the radial vibration. Now, the frame may also be considered as a deep ring, with a ratio of outside to inside diameter of the same order of magnitude as the core. Consequently, the tangential vibration at the *inside* diameter of the frame is likely to be about 80 per cent of its radial vibration. Thus, if the point of attachment for a tangentially rigid core mounting is at the outside diameter of the core, something like 20 per cent of the radial vibration of the core would be tied in rigidly with 80 per cent of the radial vibration of the frame. The result would be a reduction of about four to one in the radial vibration at the surface of the frame. Such an improvement would be quite worth while, but it was felt that a higher ratio of reduction would be desirable.

Importance of Natural Frequency of Stator Frame

Consideration of a resilient mounting having both radial and tangential flexibility indicated that an improvement ratio of 10 or 20 to 1, or even higher, could be obtained by suitable design of the spring members and the frame. In brief, the spring members must be relatively flexible, and the frame relatively stiff. The static performance of such a combination is readily calculated. The vibrational loading of the frame is computed as the product of the amplitude of the core and the gradient of the spring members. This neglects the yielding of the frame, which is intended to be negligibly small anyway. Both tangential and radial loading must be taken into account. However, the running performance depends upon the natural frequency of the frame, in the same manner as the running amplitude of the core depends upon its natural frequency. Strictly, the core, spring members, and frame form a compound elastic system with two natural frequencies, both of which are different from the natural frequencies of the core and frame considered separately. The behavior of such a system has been carefully worked out by methods described in chapter V of reference 4. With the aid of some simplifying assumptions, however, calculation of the running performance to a close degree of approximation can be made, using the ordinary basic resonance curve of figure 6. The effect of the frame and spring members on the stiffness, natural frequency, and running amplitude of the core is neglected; but a correction to the natural frequency of the frame due to the spring members may be required, especially if the frame frequency is low, below 120 cycles. The static deformation of the frame, which would be produced by the combined radial and tangential loading due to the *running* amplitude of the core acting on the spring members is calculated, and multiplied by the "build-up" factor based upon the natural frequency of the frame.

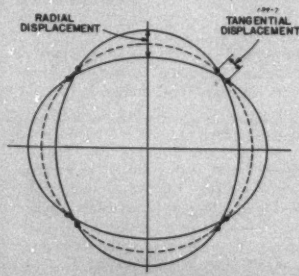

Figure 7. Sketch illustrating tangential displacements for a thin ring

For this purpose, it is of course necessary to know the four-node natural frequency of the frame. To date, it has been necessary to use test information on this point. Test equipment available for vibrating turbine wheels and buckets has been used with the addition of some small but powerful a-c magnets, which are set to pull diametrically across the bore of the frame under test. Even the largest and heaviest frames are set into vibration in this way, and by varying the frequency of the a-c supply to the magnets, the resonant frequency of the frame is readily determined. In general, it is felt that a high natural frequency (above 120 cycles per second) is desirable for frames to be used with resiliently-mounted cores, for the reason that it avoids a "critical speed" or resonance peak of frame vibration which would otherwise occur below running speed, if the generator is brought up or down with excitation. It is undoubtedly practical, however, to use resilient mountings with frames having natural frequencies below 120 cycles, if the frame can be well damped to limit the momentary vibration encountered in passing through resonance, or if the excitation is reduced sufficiently or removed at that speed.

Mechanical Effects of Rotor Unbalance and Short-Circuit Torque

So far, the discussion has centered about the functioning of the resilient core mounting to isolate the magnetic vibration. Now, attention is directed to possible difficulties from other sources.

The core, end flanges, and winding structure, taken together, comprise by far the heaviest part of a two-pole generator. If "floated" on spring members, there is the possibility that mechanical resonance might take place for bodily motion of this heavy mass in response to stimulation coming from rotor unbalance. Considered as a simple mechanical system with the frame support on the

foundation assumed to be rigid, the obvious solution is to make the natural frequencies of the core on the spring members low for both translation, i.e., "straight bouncing," and for rotation about an axis at right angles to the shaft, which can be called "rocking." Actually, the foundation is never rigid; for large machines it is far from being so, especially in the horizontal plane. The result is a complicated elastic system, comprising the rotor, the frame, and the spring-mounted core (not to mention the turbine), all mounted on a foundation of considerable mass and with flexibility both for horizontal and vertical motion. Such systems have been investigated by E. H. Hull, using a novel experimental technique described in a recent paper.[7] He finds a whole series of resonance speeds, depending upon the critical speeds of the rotor (as calculated for rigid bearing supports) and the natural frequencies of the spring-mounted core, as well as the mass and flexibility of the foundation. Fortunately, it seems to be possible to control these resonance speeds, for ordinary values of shaft criticals and foundation characteristics, by making the natural frequencies of the spring-mounted core rather low, say, of the order of 1,200–1,500 vibrations per minute. Also, none of them involve much vibration if the machine is properly balanced.

Special consideration must also be given to the severe transient short-circuit torques characteristic of turbine generators, in order that the spring members shall not be overstressed. Instantaneous peak values of the applied torque, although they may be many times normal rated torque, are ordinarily not high enough to cause concern in this respect. Their magnitude is usually of such an order as would about take the gravity load off one foot of the generator and double it on the other. Since the considerable inertia of the core is interposed between the short-circuit torque, applied at the air gap, and the spring members outside the core, the stresses in the spring members are not a direct function of the applied torque alone but depend upon the torsional displacement of the core relative to the frame. This displacement can be calculated by methods[8,9] previously developed for analysis of short-circuit torques at the couplings of turbine-generator sets.

These methods are rather well known, but a few remarks about them might be in order here. The simplest approach considers the torques as suddenly applied, but neglects the decrements, and assumes a rigid foundation such that the torsional system has only one natural frequency. On this basis, the maximum displacement may be computed as the sum of a series of components of displacement which occur at the applied torque frequencies (principally 60 and 120 cycles) and also at the torsional natural frequency of the system. Each of these components is a function of the frequency ratio (impressed frequency/natural frequency), in a manner very similar to the basic resonance curve of figure 6. However, it appears advantageous in this case to keep the torsional natural frequency well below the lowest frequency of the impressed torque. When foundation flexibility is taken into account, the system becomes a compound one with two natural frequencies. The analysis becomes considerably more elaborate but has been worked out fully on the basis of neglecting the mechanical damping and the torque decrements. These assumptions, of course, are on the safe side, but before this study of short-circuit torques can be considered complete, these factors must be taken into account. In general, however, it is found that foundation flexibility reduces the maximum displacement of the core relative to the frame below that which would occur on a rigid foundation.

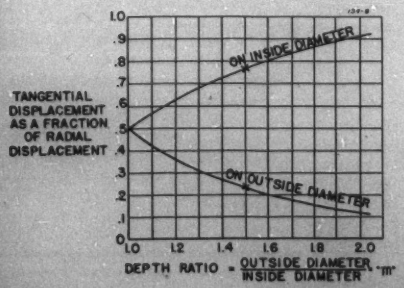

Figure 8. Tangential displacements in deep rings

Description of Resilient Core Mounting as Built

A resilient core mounting and a nonresonant stator frame were designed along these lines for a 31,250-kva air-cooled generator. A photograph of the frame is included as figure 9, and figure 10 gives a close-up view of the assembled spring members. These are twin sets of spring bars of rectangular section, attached by bolting and welding to the bore of the frame and arranged in three groups lengthwise. The long dovetail key bars on which the core is stacked, are attached by body-bound studs to the centers of the spring bars, which provide a sturdy tie between the core and the frame, rigid lengthwise but with some

Figure 9. Frame of 31,250-kva generator with resilient core mounting

flexibility both in the radial and tangential directions. The spring bars are really beams with fixed ends, and with heavy bosses at their centers where they are bolted to the dovetail key bars and also at their ends where they are attached to the frame, so that there are no moving joints to wear out. Fatigue seems to be completely out of range for these bars, as the alternating component of stress is of the order of two per cent of the elastic limit of the material, superposed upon steady gravity stresses of about 20 to 25 per cent. And fatigue needs to be out of range, as at 120 cycles per second these bars must undergo more than 10,000,000 cycles of duty per day. The frame was also specially designed, to have a high four-node natural frequency, well above 120 cycles. The test value on the bare frame, without end shields, was 201 cycles. On this basis, the expected performance of the resilient core mounting was a reduction of the magnetic vibration from core to frame of about 30 to 1. When this machine came to test at the factory, it met our expectations fully. In fact, no 120-cycle vibration could be detected at the middle of the frame, by touch or by

Figure 10. Close-up view to show spring bars in 31,250-kva generator

means of optical vibration indicators, Frahm vibrating reed tachometers, or a vibration-velocity pickup device connected to a cathode-ray oscillograph. The core was reached by means of rods inserted through small holes drilled in the frame, and showed about 1.3 mils of magnetic vibration. But it was impossible for a man standing alongside the generator to tell, by touch or by hearing, when excitation was applied or removed.

Operating Results

This 31,250-kva air-cooled generator, as built with resilient core mounting and nonresonant stator frame, was installed at the Westport plant of the Consolidated Gas Electric Light and Power Company of Baltimore, Maryland, and went into service on August 10, 1940. Figure 11 shows this generator and driving turbine as installed at Baltimore.

The turbine driving this generator was built for operation at a throttle pressure of 1,250-pounds gauge 900 degrees Fahrenheit, being supplied with steam from two high-pressure boilers. The turbine exhausts into the 200-pound steam mains of the earlier Westport plant but with piping arranged for specific superposing if desired on two 25,000-kva 200-pound regenerative condensing units, which were the last 200-pound units installed at Westport.

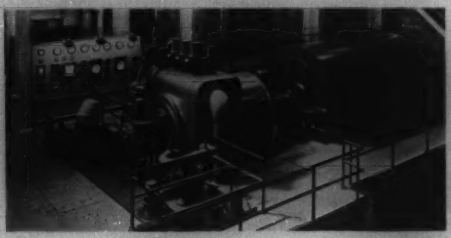

Figure 11. Turbine unit with 31,250-kva generator having resilient core mounting, Westport plant, Consolidated Gas Electric Light and Power Company of Baltimore, Md.

The operation of this superposed 3,600-rpm unit has well demonstrated the value of the new core mounting for suppression of 120-cycle core noise and vibration, the operating results being quite in agreement with the factory tests. In actual service, a man standing alongside of the machine could not detect by touch or hearing the application or removal of field excitation.

Other machines incorporating the improved type of core mounting are now being built, and it is expected that this feature will be applied to many 3,600-rpm generators of the future.

References

1. Special Problems of Two-Pole Turbine Generators, **C. M. Laffoon** and **B. A. Rose**. AIEE Transactions, volume 59, 1940 (January section), pages 30–3.

2. The Design of Large Electrical Machine Frames, **Ralph Poole**. *Journal* of the Institute of Electrical Engineers (England), volume 77, 1935, pages 176–88.

3. Strength of Materials (book), **S. Timoshenko**. D. Van Nostrand Company, part II (2nd volume), 1930, pages 434–8.

4. Vibration Prevention in Engineering (book), **A. L. Kimball**. John Wiley and Sons, 1932, page 30.

5. Vibration Problems in Engineering (book), **S. Timoshenko**. D. Van Nostrand Company, 2nd edition, 1937, pages 14–16.

6. Theory of Sound (book), **Lord Rayleigh**. MacMillan and Company, 2nd edition, volume 1, 1894, page 388.

7. The Effect of Foundation Stiffness on the Resonant Frequencies of Rotating Machines, **E. H. Hull**. *Journal of Applied Mechanics*, volume 8, 1941.

8. Single Phase Short Circuit Torque of a Synchronous Machine, **Nickle, Pierce,** and **Henderson**. AIEE Transactions, volume 51, 1932, pages 967–73.

9. Transient Torques in Synchronous Machines, **M. Stone** and **L. A. Kilgore**. AIEE Transactions, volume 52, 1933, pages 945–53.

High-Potential Testing Equipment for Quantity Production

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Introduction

MANUFACTURERS of electrical apparatus and appliances are aware of the value of high-potential insulation tests and have endeavored constantly to improve testing facilities and methods. Practical circumstances very early gave rise to the practice of applying a short-time test voltage substantially above the normal excitation of the apparatus or appliance. Because of the availability and simplicity of amplitude control, alternating voltage of ordinary power frequency has been used and the test voltage levels have been developed through operational experience. Occasionally circumstances have made the use of power frequency impractical; hence higher frequencies and direct voltage have been resorted to. Also, surge voltage tests have been used increasingly in an effort to simulate transient voltages which occur in field circuits.

For large apparatus and for high-voltage equipment the dielectric testing sets have been standardized and the testing procedure has been generally established. In this field a generous amount of time can be allowed for conducting tests, because the quantity of apparatus manufactured is comparatively low.

Because of the large quantity of small apparatus and low-voltage equipment now manufactured, high-potential testing must be co-ordinated with production circumstances where rates of 20 or 30 complete dielectric tests per minute are commonly encountered. Accordingly, the recognized practice of gradually raising and lowering the test voltage is entirely impractical from the standpoint of time consumed. Consequently many of the factors which have been so carefully considered in the high-voltage field have been neglected in low-voltage testing.

The purpose of this paper is to point out that the simplicity of low-voltage testing does not obviate surge voltages and that the same general fundamental factors established for high-voltage testing also apply to low-voltage testing. In this paper an attempt has been made to evaluate the surge voltages in terms of their effect on the breakdown of insulation. First, a cathode-ray oscillograph study was made to determine the magnitude of the surges. Then a number of comparison tests were made on a selected insulation to determine the comparative breakdown strength with and without influence of the surges.

As a result of these investigations it was found that the magnitude of the surge voltage varied considerably depending on the method used for limiting the short-circuit current and on the characteristics of the dielectric. In some instances, surges of 100 per cent above the normal test voltage were measured. In a controlled test, the surges reduced the apparent breakdown voltage of a specific insulation by roughly 25 per cent. It has been found that a properly co-ordinated high-potential transformer and a resistance potentiometer control forms a suitable system for testing low-voltage apparatus. The system is relatively free from surge voltages and it does not interfere with high-speed testing. This method also has led indirectly to the development of a cathode-ray fault detector which has been very useful in analyzing the physical characteristics of the dielectric and the type of failures that occur.

Present Practice

The testing equipment for this low-voltage apparatus can be obtained and installed with comparative ease in any production line. The test voltage can be conveniently controlled and easily applied. Usually, some means of limiting the short-circuit current is employed in order to minimize the material damage to the apparatus or appliance in case the dielectric fails. A pair of insulated electrodes, called stickers, permanently connected to the high-voltage terminals of the high-potential transformer, is commonly used to apply the test voltage between the windings and the frame or ground of the apparatus under test. In some cases, however, two or more units may be connected in parallel to the high-potential testing transformer which is then energized for a brief period of time. In either case, surge voltages are liable to occur in the high-voltage circuit which casts some doubt on the effective value of the test voltage.

Switching Surges

It is common knowledge that the interruption of the excitation circuit of a transformer will produce a transient voltage across its terminals. The amplitude of the impulse is proportional to the rate of change of flux in the magnetic circuit, and it is dependent on the position on the

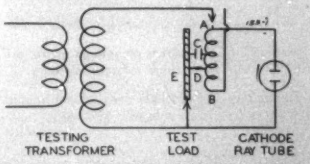

Figure 1. Equivalent high-potential testing circuit

A—Arc
B—Winding of apparatus
C—Capacitance of winding to ground
D—Resistance of insulation
E—Frame of apparatus (ground)

Figure 2. Oscillogram of voltage across dielectric during high-voltage switching

Transformer controlled by variable-voltage autotransformer
Normal crest voltage—3,530 volts

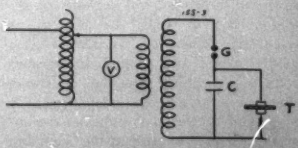

Figure 3. Test circuit for evaluating effect of switching surges on dielectric strength of paper

G—Sphere gap
C—Capacitor equivalent to the capacitance of low-voltage apparatus
T—Test sample

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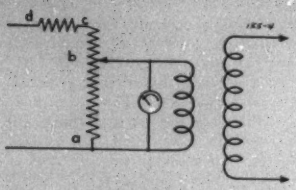

Figure 4. Potentiometer-controlled testing transformer

Minimum series resistance—d-c
Maximum parallel resistance—c-a

Figure 5. Oscillogram of voltage across dielectric during high-voltage switching

Transformer controlled by potentiometer
normal crest voltage 3,530 volts

flux-time curve at which the circuit is opened. Whenever high-potential testing methods employ low-voltage switching, it is obvious that the dielectric circuit will be subjected to an indefinite abnormal voltage. Furthermore, the maximum amplitude of the surge may occur when the transformer is de-energized at the conclusion of the test. The dielectric may fail at this final instant and if it does, it may not be detected unless a subsequent test is made.

High-voltage switching is employed every time the stickers are applied and removed from the apparatus. An arc occurs when the stickers are applied and another when they are removed. The testing circuit, consisting of resistance, inductance, and capacitance, may have excessive transient voltages induced in or applied to all parts of the circuit during this arcing period.

A cathode-ray oscillograph connected as shown in figure 1 will indicate the actual voltage to which the dielectric is subjected. When the contact at *A* is solidly closed the normal transformer voltage is applied to the dielectric. However, when an arc is established at *A* a series of transients or impulses are impressed on the test piece at the beginning of each one-half cycle. The oscillogram in figure 2 shows this condition for a common type of testing circuit. This shows a crest voltage of over 5,000 volts whereas the steady-state test voltage had a crest value of 3,500 volts. This is somewhat equivalent to superposing an impulse on the power frequency. It has been observed in the past that under these conditions a flashover of an insulation may not be followed by a power arc, particularly when the total voltage amplitude is near the flashover value for that insulation. Under the somewhat similar conditions as illustrated by figure 2, the insulation may be partially damaged, by a pinhole puncture, for example, which has not been followed up by a power arc. This may be a sufficient cause for a future failure at a lower test voltage. This experience indicates that it is desirable to maintain a sinusoidal voltage on the test piece throughout the entire test period.

Field Data

In order to obtain some field data on the effect of arcing surges some special tests on fractional-horsepower motor armatures were conducted with a pair of stickers connected in parallel with the regular production line. The armatures were tested at 1,500 volts, but would normally withstand 2,500 volts. The test pair of stickers was connected to an armature and an arc maintained between one sticker and the winding for a period of time. Five consecutive armatures were broken down on the production line during this test, although a voltmeter still indicated an rms test voltage of 1,500 volts.

Table I. Effect of Surges on Dielectric Strength of Paper

Sample Number	Breakdown Voltage—No Arcing (Voltmeter Readings)	Breakdown Voltage Arcing to Simulate Removal of Stickers (Voltmeter Readings)
1	1,330	1,170
2	1,670	1,330
3	1,700	1,280
4	1,860	1,375
5	1,430	1,265
6	1,460	1,170
7	1,400	1,230
8	1,670	1,330
9	1,530	1,350
10	1,400	1,200
11	1,370	1,140
12	1,310	1,150
13	1,370	1,170
14	1,400	1,220
15	1,670	1,330
16	1,700	1,310

In another instance, a plate-glass condenser was used as a dielectric load and during the arcing period a sufficiently high-surge voltage was established to flash over the one-fourth-inch plate glass of the condenser, although the test voltage as indicated on an instrument remained at 2,500 volts. The condenser had a sinusoidal flashover value of 6,000 volts.

A test circuit shown in figure 3 was established to measure the effective breakdown value of the surges initiated by an arc in the high-voltage circuit. The sphere gap *G* represents the stickers and it was used merely to control the arc and not to measure voltage. Past experience has indicated that the capacitance of the dielectric of low-voltage apparatus and appliances varies from 0.0005 to 0.002 microfarad. A 0.001-microfarad capacitor, chosen as a representative load, was connected in series with the gap so that the voltage across it is comparable to that across the dielectric of the apparatus in actual practice. A transformer having about three per cent reactance was used for the source of high potential. Several selected samples of an insulation, consisting of four layers of 0.0005 condenser paper, were used as test specimens and connected directly across the capacitor. Each specimen was large enough to obtain two breakdown tests, one when a sinusoidal voltage was applied and the other when surges were produced by the arc. The first test was obtained by closing the sphere gap *G* and raising the primary voltage very slowly by means of a variable-voltage autotransformer until breakdown occurred. The second test was obtained by setting the primary voltage at some low value and opening the gap *G* until the arc was extinguished. (This action simulates the removal of stickers from the apparatus.) The sup-

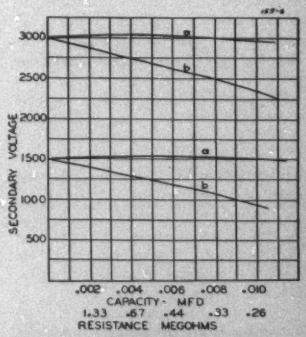

Figure 6. Voltage-regulation curve of 0.25-kva 3,000-volt potentiometer-controlled transformer

a—Capacitance load
b—Resistance load

ply voltage was raised in small increments and the procedure repeated until the specimen broke down and in each case the rms voltmeter readings were recorded. The results, shown in table I, indicate that the breakdown voltage is 20 per cent lower when the surges are present or in other words the dielectric is subjected to a higher level than the voltmeter indicates.

Surge voltages varying from 25 per cent to 100 per cent above the test voltage are commonly found in testing installations employing stickers, and utilizing reactance to limit the short-circuit current. Even when reactance is not deliberately introduced to limit the current, and when a testing transformer of normal design with less than five per cent reactance is used, the surges are still present. They may not be severe for many types of apparatus where the factor of safety is large. Furthermore, the degree of damage the surge can create in the insulation has not been conclusively established. The serious factor involved, however, is the uncertainty of the actual voltage to which the dielectric is subjected.

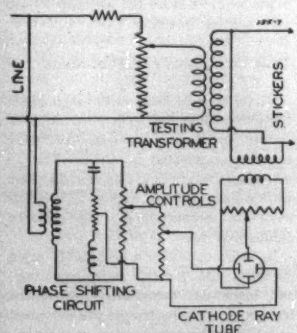

Figure 7. Circuit diagram for potentiometer-controlled testing transformer and cathode-ray fault detector

Methods of Reducing Surge Voltages

Resistance inserted in the high-voltage circuit in series with the test load will greatly reduce the surges appearing across the dielectric. In one case it was found that 50,000 ohms in the secondary of a 0.25-kva low-reactance transformer reduced the surges to a negligible amount. An equivalent resistance on the low-voltage side of the transformer similarly reduced the surges. A circuit shown in figure 4 has been found to be relatively free from all types of surges caused by low- or high-voltage switching, because the parallel resistance tends to absorb the energy of the low-voltage switching.

The effectiveness of the potentiometer control was demonstrated in the following manner. A transformer with a rating of 0.25 kva with three per cent reactance and a secondary voltage of 2,500 volts with 110 volts on the primary was supplied from a variable-voltage autotransformer. Surge voltages initiated by low-voltage and high-voltage switching were measured across a 0.003-microfarad capacitor load. The value of the surge most often obtained is given in table II as a percentage of the open-circuit secondary peak voltage.

Table II. Surge Voltages in a Circuit Controlled by a Variable-Voltage Autotransformer

	Surges in Per Cent of Normal Secondary Peak Voltage	
Normal Secondary Voltage	Primary Switching	Secondary Switching
2,500	200	250
1,500	200	200
900	200	200

The variable-voltage autotransformer then was replaced by a potentiometer, or a resistance control as in figure 4 and the switching repeated. The results are shown in table III. A typical oscillogram of the high-voltage switching surge is shown in figure 5, and compares with figure 2 for the previous case. Satisfactory operation is thus assured with the potentiometer control if the series portion is limited to some predetermined minimum value of resistance and also if the parallel portion is limited to some maximum value.

Any type of testing circuit will supply a limited load when some means of current limitation is employed. Figure 6 shows the voltage-load curves for a potentiometer-controlled circuit. The capacitance of the dielectric circuit does not have a great effect on the regulation, curve *a*, especially in the range encountered in low-voltage apparatus. The resistance of the dielectric, however, does cause an appreciable regulation, curve *b*. Therefore, if it is desired to maintain a regulation of less than three per cent the resistance of the dielectric should not be lower than three megohms.

The high-voltage wave form can be maintained reasonably sinusoidal. If the series resistor alone is used, the normal exciting current required by the transformer causes an appreciable voltage distortion. If, however, the current through the resistor *ab* in figure 4 is approximately three times the value of exciting current, the wave form is acceptable, with a harmonic content of less than five per cent. The amount of distortion, of course, depends materially on the degree of saturation in the transformer core, but if this is maintained at a reasonable value, a good high-voltage wave form can be maintained.

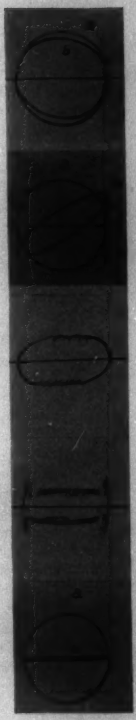

Figure 8. Lissajous figure of test voltage

a—Open circuit
b—Resistance load

Figure 9. Lissajous figure of test voltage

a—Open circuit
b—Capacitance load

Figure 10. Lissajous figure of test voltage with corona in insulation

Figure 11. Lissajous figure of test voltage when arc is jumping through insulation

Figure 12. Lissajous figure of test voltage

a—Open circuit
b—Short circuit

Fault Detection

The arrangement of resistors just discussed permits an easy detection of short

Table III. Surge Voltages in a Circuit Controlled by a Potentiometer

			Surges in Per Cent of Normal Secondary Voltage	
Normal Secondary Voltage	Series Resistance (Ohms)	Parallel Resistance (Ohms)	Primary Switching	Secondary Switching
2,500	73	250	104	100
1,500	420	250	103	100

circuits because the voltage on both sides of the transformer drops in accordance with the severity of the failure in the dielectric. If the organic dielectric materials are moist, due to high humidity, the conduction current will be high, and the transformer regulation will cause the voltage to drop. Usually a high-leakage current will not destroy the insulation, but it will cause a definite indication of some abnormal condition.

A cathode-ray oscilloscope has proved to be a very useful tool in connection with the testing circuit shown in figure 4 for analyzing the type of faults that may occur in dielectrics.

Cathode-Ray Oscilloscope Fault Detector

Figure 7 shows the circuit diagram of the dielectric testing transformer, potentiometer, and cathode-ray circuit. The adjustable phase-shifting circuit permits the voltage on the horizontal plates to be shifted 90 degrees from the test voltage. The amplitude of voltage on both the horizontal and vertical plates can be adjusted so that the image on the cathode-ray tube screen can be made to appear as a circle as shown in figure 8*a* for the normal test voltage. When voltage is applied to a test sample through the stickers, the image will remain unchanged if the dielectric is perfect. If the insulation contains excessive moisture there will be a high value of conduction current, hence the voltage on the vertical plates will drop and the image on the cathode-ray tube will change to an ellipse as in figure 8*b*.

A high-capacitance current flowing through the dielectric, will cause a phase shift in the test voltage, hence the image will appear as an ellipse with an inclined axis as in figure 9*b*. Corona streamers in the dielectric will cause the image to appear as shown in figure 10, while an arc jumping across or through the insulation will change the image to figure 11. A complete short circuit produces a horizontal line as in figure 12*b*.

Conclusion

The data presented in this paper is by no means conclusive. It does not infer that all types of high-potential testing equipment are dangerous to insulating material, nor does it prove that all testing methods are improper. It has brought out the possibility that indefinite surge voltages may exist and that these surges may cause some damage to the insulation. These hazards arise, however, only when some fundamental principle has been violated, such as low- and high-voltage switching. The use of resistance for reducing surge voltages is not new. It has been shown, however, that either low-voltage or high-voltage switching may be employed without creating dangerous surges when the resistance is properly used. Thus, high-speed testing may be conducted to meet any production requirement and at the same time a definite predetermined test voltage can be maintained. There may be other methods of accomplishing the same result, but the resistance control seems to be the most expedient.

The cathode-ray fault detector is a very useful tool in connection with the resistance-controlled transformer. It enables one to determine by a glance, the wave form and magnitude of the test voltage, some of the physical properties of the insulation, and whether or not streamers or corona are present. The voltage which a material will withstand can be readily determined, and unseen flashovers can be detected by careful observation of the screen. If the power arc follows the flashover either momentarily or continuously, it too can be observed. The cathode-ray fault detector may not be practical to use in high-quantity production because of the longer time consumed in making the observations, but it is very useful in laboratory or other work where time is not so important.

Arc-Backs in Ignitrons in Series

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Synopsis: Theory based on the random occurrence of arc-backs indicates that the arc-back rate of ignitrons in series should be very low compared with the arc-back rate of the individual ignitron operating alone on its share of the voltage. To check these ideas, experiments were carried out with high-current ignitrons (350 amperes average per anode) operating in series with voltages balanced and unbalanced, and individually. The results of these tests are given and discussed.

Introduction

THE ignitron is a single-anode mercury-vapor rectifier with a mercury-pool cathode and a stationary electrode, called the ignitor, partially immersed into the cathode pool. A current of a few amperes at about 100 volts passed through the ignitor initiates the arc once each cycle and at any time desired in the cycle. The use of ignitrons with the usual rectifier-transformer connections gives a power-converting system with all the advantages of grid-controlled rectifiers at higher efficiencies, since no grids are required near the anode for the control of load.

In the last few years the use of ignitrons commercially has been greatly accelerated and single assemblies up to 3,000-kw capacity at 600 volts are in service.

Research work continues on the still baffling problem of arc-back. Accepting the arc-back rates as obtained on commercial tubes, however, it seemed desirable to check whether the lower arc-back rate for ignitrons in series, as predicted by the theory of random arc-back could be really obtained.

Two ignitrons were tested in series and individually, at water temperatures abnormally high, and without baffles and shields, so that arc-back rates were high enough for conclusions to be drawn in not too excessive a time. It was found that the two ignitrons in series under these conditions would operate with an average of 13.75 hours per arc-back, whereas an individual ignitron at *half the voltage* would operate with an average of only 0.0442 hours between arc-backs. The calculated value was 16.4 hours per arc-back for the two ignitrons in series.

Test Conditions and Procedure

All tests were made with single-phase full-wave connection from 540-kva transformer bank to two 375-volt, 300-kw d-c machines connected in series. The ignitron tanks were eight inches in diameter with 6-inch graphite anodes 2¾ inches from the mercury pool. No grids or baffles were used.

In order to obtain a reasonably rapid arc-back rate for the series operation, and hence not excessively prolong the test, the water temperature was increased

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until the arc-back rate was a value which would give rates for series operation of roughly one arc-back per day. It was found that at 700-amperes load and a cooling water-temperature range of 55 begrees to 67 degrees centigrade the arc-dack rate was satisfactory for the test. A current of 700-amperes load is 350 amperes per anode and is not too high for a 6-inch diameter graphite anode.

With conditions as stated above, the ignitrons were operated at 300 volts direct current, one at a time, until ten arc-backs had occurred for each ignitron. These data established the arc-back rate for the individual ignitron for 300-volt operation. Next, the tubes were connected in series and operated balanced (6,000 ohms across each ignitron) or unbalanced (1,000 ohms across one and 75,000 ohms across the other) at 600 volts. After completion of this series test, one ignitron was again operated at 300 volts to check if arc-back rate had changed during the experiment. During this test rates were also obtained for 300 volts by counting breakdowns, on one of the two ignitrons by means of a cathode-ray oscillograph, when the tubes were operating in series at 600 volts with voltages balanced.

The arc-back rate for 600-volt operation of *one* ignitron only was obtained by unbalancing the tubes in series with parallel unequal resistances and counting the breakdowns on the tube which carried almost all of the inverse voltage. From these measured rates at 300 and 600 volts, the arc-back rate for series operation was calculated with the assumption that the arc-back lasts for the whole half-cycle at which it occurs.

Results

The data as obtained in the experiment are compiled in table I. Several counts for the individual ignitrons were made of various durations varying from 5 to 38 minutes. The total time for counting is about the same for the 300- and 600-volt tests. From these data we find that the average time between arc-backs for ignitrons in series is 16.4 hours, when calculated from the arc-back rates of the individual ignitrons, whereas the measured average time between arc-backs is 13.75 hours. These values are for the balanced condition and check reasonably well. For the unbalanced condition, the values are seven hours as measured, and four hours as calculated. The method of calculation is described in the next section.

Discussion

When two ignitrons of the same design are connected in series, the inverse voltage will generally not divide equally between them at all times during the inverse cycle. This unequal distribution of voltage occurs only during the de-ionization time and varies from cycle to cycle. From oscillograms the inverse voltage varied from 600 to 266 volts, immediately after transition, on a single ignitron, in various cycles. This varying unbalance exists, to a continually decreasing extent, for approximately 40 degrees after transition.

To calculate the arc-back rate for ignitrons in series from the arc-back rates of the individual ignitrons, it was assumed that the arc-back cause in the individual tube exists only for the cycle considered, and that complete breakdown of the ignitrons in series will occur, if with an arc-back on one ignitron, one arc-back takes place in the same half-cycle on the other ignitron.

The calculation for the average time between arc-backs for series operation was made as follows:

If

t_3 = average time in seconds between arc-backs at 300 volts, for one ignitron

t_6 = average time in seconds between arc-backs at 600 volts, for one ignitron

f = frequency in cycles per second of power source

t_s = average time in *hours* between arc-backs for series operation

then

$\frac{t_3}{2}$ = average time for one or the other of the two ignitrons when operated in series on 600 volts

After an arc-back occurs in one ignitron, the voltage on the other anode is increased to 600 volts and its individual arc-back rate is increased. The time in cycles between arc-backs under this new condition is for one ignitron only, since we are considering that two in series are used, and we have $t_6 f$ as the number of cycles between arc-backs. The product of the above factors gives the average over-all arc-back free time for two ignitrons connected in series and in terms of hours.

$$T = \frac{f t_3 t_6}{2 \times 3{,}600} \text{ hours}$$

and for 60-cycle power source

$$T = \frac{t_3 t_6}{120}$$

hours between arc-backs for the balanced condition. This equation was used to determine the arc-back free time for series operation after t_3 and t_6 had been measured.

For the unbalanced case, t_6 is used twice and since the voltage before an arc-back is practically zero on one of the

Table I

Ignitron	Resistance Across Other Ignitron	Volts	Amperes	Time of Count in Minutes	Number of Arc-Backs	Average Time Between Arc-Backs in Seconds T
3A48-2	None	300	700	21	6	210
3A48-1	None	300	700	25	7	214
3A48-2	None	300	700	38	10	228
3A48-2	6,000	300	700	19	26	46
3A48-1	6,000	300	700	10	5	120
3A48-2	6,000	300	700	10	4	150
	6,000	300	700	8	6	80
3A48-2	1,000	300	700	15	4	225
		For 300 volts average time between arc-backs = 159 seconds				
3A48-2	6,000	600	700	14.5	207	4.2
3A48-1	6,000	600	700	15	61	14.8
3A48-1	1,000	600	700	14	100	8.4
	1,000	600	700	8	72	6.67
3A48-2	1,000	600	700	32	66	29.0
3A48-1	1,000	600	700	19	136	8.4
3A48-1	1,000	600	700	5	0	Water 33 degrees to 40 degrees centigrade
3A48-2	1,000	600	700	7	23	18.3
3A48-1	1,000	600	700	7	20	21.0
3A48-1	1,000	600	700	10	31	19.4
3A48-1	1,000	600	700	16	72	13.3
3A48-2	1,000	600	700	12	24	30.0
		Average time between arc-backs at 600 volts = 15.8 seconds				

NOTES: Measured average time between arc-backs for two ignitrons in series and balanced was 13.75 hours (Test time was 55 hours.) Calculated from data:

$$\frac{159 \times 15.8}{120} = 21 \text{ hours}$$

Calculated with first three values of table I omitted:

$$\frac{124 \times 15.8}{120} = 16.4 \text{ hours}$$

Measured average time between arc-backs for two ignitrons in series and unbalanced was 7 hours. (Test time was 21 hours.)

Calculated from data:

$$\frac{15.8 \times 15.8}{60} = 4 \text{ hours}$$

Electrolytic Process of Scale Removal From Steel

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ELECTROLYTIC action is by no means new or unfamiliar. It is as old as electricity itself and has been evidenced in many ways throughout the entire application and use of electricity. One of the early applications of electrolytic action pertaining to metals was employed in the refining of copper and similar metals. Also, electrolytic action was employed in the plating of metals on surfaces requiring a high finish or protective coating, which, of necessity, should be very thin. This application is best evidenced in nickel plating and chromium plating which has been widely used for a number of years.

Electrolytic action has been in general use in steel mills and other industries for cleaning steel sheets, for example, the hot caustic electrolytic scrubbing equipment for removing oil and dirt from cold-rolled sheets. This application of electrolytic action is used in conjunction with mechanical scrubbing and brushing rolls for cleaning the sheets, the electrolytic action being a primary and the scrubbing action the secondary means for obtaining this result. It, therefore, may seem strange that this very familiar and well-known principle of electrolytic action which has been in wide and rather diversified use for so long a time has not been applied to pickling or the removal of scale from steel in a sulphuric acid bath.

The answer to this, we believe, is due to the physical and mechanical difficulties encountered when trying to apply electrolytic action in a sulphuric acid bath. There are many physical difficulties encountered when a combination of electrolytic action and sulphuric acid pickling action are combined. This can be readily understood when it is realized that electrolytic action in combination with sulphuric acid is decidedly destructive to any current-carrying metal such as nickel, copper, aluminum, or steel. Also, sulphuric acid is an active agent in decomposing some of these materials, particularly steel. Therefore, the reluctance in applying electrolytic action to the pickling of steel which involves the use of sulphuric acid, has, no doubt, largely been due to these physical difficulties encountered rather than a lack of appreciation of the benefits derived from such an installation.

Development

In the processing of flat-rolled steel, it is necessary to remove the mill scale and oxide from the entire surface of the steel which is usually produced in coils of various widths and lengths. To remove the mill scale from these coils of steel, the normal procedure is to run the strip steel through a continuous pickling line which consists of a series of tanks arranged in tandem, filled with approximately a ten per cent solution of sulphuric acid and provided with the necessary mechanism to permit the strip steel to be uncoiled and fed through the pickling line in a continuous strip, the strip being delivered at the finishing end with the scale removed by the action of the sulphuric acid in which it has been submerged. Any practical application of electrolytic action which might be used in augmenting or improving the pickling action described above, should be applied to the existing continuous pickling line and would take the position of being additional apparatus applied to this already standard equipment.

On account of the physical difficulties mentioned above, it would therefore follow that considerable experimentation would be required to develop a feasible working assembly of equipment that would have commercial application in a continuous pickling line. With this viewpoint in mind, a number of years were spent in experimenting and developing this electrolytic equipment. Early experiments were made to determine the feasibility of using either direct or alternating current, and it was found that practically equally satisfactory results could be obtained with either of these currents.

Another problem was the method of applying the current to the sheet of steel which was to be pickled, bearing in mind that since this sheet steel is being continuously fed through the pickling line, it would be necessary that any current-carrying device that made contact with the strip would have to be in the form of a roller or some similar contacting device. This, in itself, presents quite a problem, as the contacting medium would be submerged in a sulphuric acid bath and would also be carrying electric current. This naturally would result in the contact

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1. For numbered reference, see end of paper.

tubes, it is not necessary to divide by two, as was done above. The arc-back free time for the unbalanced case will be

$$T = \frac{t_b t_a}{60} \text{ hours}$$

Following table I the calculations are shown for the two cases. In the balanced case two values are given; namely, 21 hours and 16.4 hours. In obtaining the latter value, the first three values of table I were omitted. It is believed that they are high because the time ignitrons were "off the line" after each arc-back is an appreciable fraction of the operating time. This allows the tubes to cool somewhat, and higher times may, therefore, be measured. Also the unbalance due to ionization variation made these three tests of uncertain value.

When the ignitrons were connected in series and the parallel resistance across an ignitron was 1,000 ohms, an arc-back in an individual ignitron, as determined by the cathode-ray oscillograph, would continue to the end of the half-cycle at which it started. However, with 6,000 ohms an arc-back would often clear before the end of the half-cycle. This instability is characteristic of arcs when the current is limited.

Conclusions

Experiments verify that the arc-back rates of ignitrons operated in series can be calculated from their individual arc-back rates. This indicates an advantage in direct series operation of ignitrons for high voltage, rather than placing ignitrons with their associated transformers in series.

material being eaten away rather rapidly by the electrolytic action and, in most cases, would result in depositing a coating of this material on the strip steel which is to be pickled.

From experimentation, it was found that the amount of current necessary to obtain proper electrolytic action in the removal of scale was from 100 amperes to 150 amperes per square foot of the strip steel being pickled. This large amount of current, if applied directly to the steel strip, would require contact rolls at frequent intervals throughout the length of the steel strip to equally distribute the current over the entire surface of the steel. Due to the difficulty encountered in applying the current in this way, it was decided to place current-carrying electrodes in the pickle bath, these electrodes being spaced on either side of the steel strip top and bottom, the strip allowed to pass through the sulphuric acid pickling bath between these electrodes. Then, by applying alternating current to these electrodes, the current would continuously pass back and forth between the electrodes and, in so doing, would pass through the sheet, in this way setting up an electrolytic action on the sheet materially assisting in the removal of the scale. This scheme was adopted and top and bottom electrodes, spaced apart, were installed in the pickling tanks and means provided for carrying the strip continuously through the tank between these electrodes.

The next consideration was the proper material to use in forming these electrodes. Considerable experimentation was carried on in this matter and, after trying out many different materials, it was found the most satisfactory material was graphite slabs which could be made up into electrodes of any required size by the assembly of these slabs into a unit of the required dimensions. Each pickling tank is approximately 60 feet long and of a width sufficient to allow the passage of the widest steel strip, which means that these tanks, in some cases, are eight feet wide. Since it was important that the electrolytic current be, as near as possible, uniformly distributed throughout the entire length of the submerged sheet, it was decided to install a number of electrodes in each tank rather than a single top and bottom electrode which would extend the entire active length of the tank. Consequently, these electrodes were designed to a dimension that would correspond to the width of the tank and allow a multiple number of electrodes to be installed throughout the length of the tank. This resulted in a final selection of six top and six bottom electrodes being installed in each pickling tank. The actual dimensions of these electrodes, in our case, were about four feet two inches wide and six feet six inches long and were installed in a pickling line that was designed for accommodating a maximum width steel strip of 44 inches.

To further insure uniform distribution of current, means were provided for bringing current into each electrode at four points. Each pickling tank was supplied with current from two transformers, each transformer feeding one-half of the electrodes in a tank. This results in a minimum length of current-carrying conductors between the transformer and the electrodes. This is an important factor to be considered when dealing with current flow of this large amount and low voltage.

The voltage required to pass the amount of current necessary through the pickling solution varies with the strength of the sulphuric acid and the content of the iron sulphate in the solution. Therefore, transformers were provided with a five-point tap changer on the primary side which would give a secondary voltage range from 15 volts down to 7 volts. The transformers were also provided with three segregated secondary windings, each winding connected direct to one top and one bottom electrode. This was done to further insure the uniform distribution of the current to the strip steel being pickled. The lower or seven-volt tap of the transformers is used when the pickling bath is first put in use, which means that there is at least ten per cent sulphuric acid solution and no iron sulphate. As the pickling action progresses, the acid is consumed resulting in a gradual lowering of the acid in the solution. Also, since the pickling action will remove a small amount of steel from the sheet, along with the scale, there will be gradual build-up of iron sulphate in the solution. These two conditions result in increasing the electrical resistance of the pickling solution which necessitates increasing the voltage to compensate for the increased resistance. This accounts for the various voltage taps mentioned above.

It is necessary to provide some means for controlling the current supply to the electrodes which is synchronized with the feeding of the strip through the pickling tanks and so connected that the electrolytic power is on only during the operation of the pickling lines and automatically shut off each time the line is stopped. This is necessary to prevent the pickling action continuing while the strip is not in motion. If this precaution was not taken, it would result in the strip being overpickled each time the line is momentarily stopped. In addition to this automatic control, there is also provided a manual control on the pickle line operator's control pulpit board.

Electrolytic action is most active after the sulphuric acid solution has penetrated through the film of scale and has reached the steel surface of the sheet. For this reason, the first tank in a continuous pickling line is not provided with electrodes, this tank being used as a conditioning tank which will allow the acid to penetrate through the film of scale. The electrodes are installed in the second and third tanks only in which the entire electrolytic action is applied and where the major part of the scale is removed. The fourth or last tank in the continuous pickling line is used only as a clean-up tank which will remove any remaining particles of scale still adhering to the steel strip.

The terminals connecting to the top and bottom electrodes carry a heavy current and it is necessary that they be well insulated to prevent current leakage and electrolytic action on these conductors. The insulating material used should be able to stand up under the action of hot sulphuric acid and acid vapor. Good grades of rubber will give very acceptable service in acid or vapor, with temperatures not exceeding 125 degrees Fahrenheit. The temperature of the pickling solution in a continuous pickling line is approximately 190 degrees Fahrenheit. At this temperature, the life of rubber is greatly reduced, therefore it is not entirely satisfactory in this service.

After considerable experimentation, we found that a glass fabric tape, impregnated with one of the synthetic insulating compounds such as Koroseal would give very satisfactory results, and this is the type of insulation that has been employed. In some of these cases, rubber is first applied to the conductors and then the glass fabric tape applied over the rubber. In others, it is applied directly to the conductor, and both installations have proved entirely satisfactory.

The steel strip forms a catenary in each pickling tank being supported on rollers in the end of each tank and allowed to dip down into the pickling solution. When electrodes are installed above the strip, it is necessary to provide some means to prevent the steel from coming in contact with the top electrodes as it travels through the tanks. Hold-down rollers were installed at each end of the electrodes in each tank. These rollers are

required to operate submerged in the acid solution and are subjected to the combined effect of hot sulphuric acid, iron sulphate, electrolytic action, and mechanical wear and shock. Materials that will stand up indefinitely in sulphuric acid, such as bronze and monel metal, will be dissipated in a very few hours when subjected to electrolytic action. Bearings have to operate submerged with no lubrication other than that of the hot sulphuric acid. These conditions are rather severe for any material that would provide a satisfactory hold-down roller.

However, a roller assembly has been developed which stands up well and gives long life and service. This consists of a roller with an extended shaft made from either carbon or a dense, compact compound using a resin base and asbestos binder. To the shaft of the roller are fitted Pyrex glass bearings. The rollers are held in position in the tanks by means of steel pipe arms which are covered with rubber, around which is applied an outer wrapping of glass fabric tape which has been impregnated with a synthetic compound. The glass bearing is fitted into a bearing housing supported by these pipes, the housing being made from the same material as the roller. This type of roller has given very satisfactory service during several years of use.

Operation

An electrolytic pickling unit, in our case, is installed on one of three continuous pickling lines.[1] This particular line is one that normally handles coils of comparatively thin gauge, narrow width, and considerable length. Due to this condition a greater speed is required on this line to produce a given tonnage in a given time than is required in the case of the other pickling lines which handle wider and heavier materials. This is the reason for the selection of this particular line to be equipped with electrolytic equipment.

The handling of coils in the feed end of a pickle line including leveling, shearing, and welding or stitching, requires a given amount of time regardless of the length of the coil. Therefore, a long coil lends itself more readily to the use of electrolytic pickling equipment than a short coil. For example, assuming a normal pickling speed of 100 feet per minute and a coil length of 200 feet: in this case, it will require two minutes for the entire coil to pass through the pickling bath. If two minutes are also required to place a new coil in the feeding equipment and perform the necessary operations such as leveling, shearing, and welding, the time of the two operations balance and there is no necessity for installing electrolytic pickling equipment in order to increase the pickling speed which is limited by the feeding operations. On the other hand, assume that the coils are available twice the length specified, or 400 feet and since the feeding time would be the same regardless of the length of the coil, electrolytic equipment could be installed to advantage, as the feeding operation would permit, in this case, a pickling speed as high as 200 feet per minute. Therefore, it is readily seen that the length of coil available has an important bearing on the advisability of applying electrolytic equipment in order to obtain additional pickling speed.

In any continuous pickling line there will be found a large variation in pickling speeds. A given line may, at times, operate at a speed of 120 feet per minute and at other times may be able to remove the scale and do a perfect pickling job on the steel at 200 feet per minute. This wide range of pickling speed is due to a number of factors, such as coiling the steel hot, or somewhat cooled before coiling in the hot mill, coils stacked hot and allowed to cool before pickling, or coils being pickled while still fairly hot, high phosphorus or high carbon steel. There are also other factors that affect the pickling speed, such as the strength of the sulphuric acid solution in all or part of the tanks, and the presence or lack of iron sulphate in the pickling tanks. Any one of these factors has an effect on the speed of pickling and when a combination of a number of these factors is present, a low pickling speed will result, and ideal conditions will naturally produce the higher pickling speeds. Therefore, these conditions also have to be given consideration in considering any means relative to increasing the pickling speed of a continuous pickling line.

Any increase in speed of pickling due to electrolytic action over what can be obtained without it results in a direct increase of tonnage from the line. This tonnage is realized with no increase in labor or overhead. The only additional cost of this tonnage is the interest on investment of electrolytic equipment, its maintenance, and the cost of the current consumed. Our experience over a number of years shows that we obtain an average increase of 35 per cent in tonnage with the electrolytic equipment over what would be obtained in this same pickling line without the use of electrolytic. The electric load for the electrolytic pickling equipment is 600 kw.

When considering the interest on investment, the maintenance, and the cost of the current consumed, it is found that the cost of pickling chargeable directly to the additional tonnage that is realized due to the operation of electrolytic equipment is considerably lower than the normal cost of pickling a ton of steel without electrolytic equipment. Therefore, under the proper conditions, electrolytic equipment shows a decided saving.

Electrolytic equipment installed on a continuous pickling line will increase the speed of the line regardless of the type of scale, the amount of scale-breaking equipment, or the grade of steel being pickled. To realize the full advantage of this increase in speed and to actually secure an increase in tonnage, the pickling line must be able to operate in the time required for a coil to pass through the pickling bath at the higher speed that can be obtained from the use of electrolytic action. Under this condition an electrolytic installation will show a good return on investment. If this condition does not exist, the time saved by the use of electrolytic equipment will be offset by the delay due to preparing a new coil for feeding into the pickling line.

The handling and feeding of coils into pickling lines is constantly being speeded up. More efficient coil handling and processing equipment is being provided by the equipment manufacturers. The time required to weld and trim coils is also being steadily decreased, all of which results in the cutting down of the time required to deliver the coil to the pickling line. This creates a condition receptive to any means that will result in a faster pickling of strip steel and electrolytic pickling equipment has a most feasible application under these conditions as a definite means of securing increased production from a pickling line.

Reference

1. For complete description see ELECTROLYTIC PICKLING OF STRIP STEEL, H. W. Neblett, Association of Iron and Steel Engineers Yearly Proceedings for 1939, page 188.

Enclosed Bus-Bar Electrical Distribution Systems for Industrial Plants

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Introduction

ENCLOSED bus-bar distribution systems have come into common usage to meet the needs of industry for the greater availability of electrical power in production areas. Beginning in 1927 the automotive industry pioneered the application of enclosed bus-bar systems as a solution to the frequent recurring problem of modifying the electrical distribution system incidental to mass production changes. Since that time there has been an increased utilization of bus-bar systems by all branches of industry.

It is the purpose of the author to present in this paper a review of the fundamental electrical characteristics of such systems, discuss and describe some typical applications, and to emphasize the need for further fundamental research to meet the growing demands of industry.

The nature of industrial application requiring economy, safety, and compactness, brought about commercial designs using formed metal enclosures, porcelain or cold-molded insulating supports, and closely spaced copper and aluminum bus bars. The common industrial voltages for which commercial designs are being manufactured are: 120/240 volts, single phase, and 120/208 volts, three phase, four wire, for light; and up to 600 volts, three phase, for power.

The industrial applications of enclosed bus bars are for main feeders generally in current ratings up to 4,000 amperes, and for obtaining convenient outlets for power in current ratings, from 125 to 1,000 amperes. Both types of products are classified as "busways" in the National Electric Code, but in this paper the two types will be differentiated by the terms "feeder busways" and "plug-in busways."

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1. For all numbered references, see list at end of paper.

While enclosing bus bars in switchboard structures, bus-bar cell construction in central stations, and interconnecting busses between equipment has been common practice for years the experience and empirical data and studies made of these bus-bar applications were not as helpful as anticipated. This is explained by the fact that these designs

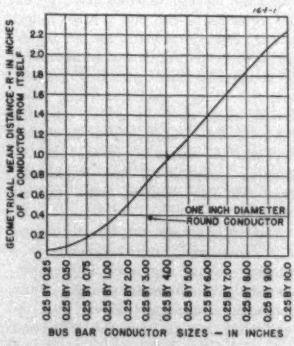


Figure 1. Geometrical mean distance of a bus bar from itself

were of rectangular bus bars on comparatively wide spacing, and in large enclosures.

As in all electrical distribution systems the important factors to be considered in planning a busway system are: voltage regulation, temperature rise, and mechanical design. The fundamental approach to the application of busways requires a determination of the impedance per unit length and current-carrying capacity of the selected design.

Voltage Regulation

Knowing the characteristics of a unit length of a selected design, the specified voltage regulation of a busway system, as for other distribution systems, is obtained by the usual series and parallel circuit connections.

Unfortunately, at present, specific unit length characteristics of busway systems are not as available in literature as for cable systems. One of the factors which contributes to this situation is that in meeting the increasingly exact service requirements of industry, the manufacturers have continued a process of evolution which in itself has not given encouragement to the publishing of tables and data. A second contributing factor is that in the tendency to closer and closer bar-to-bar spacing, skin and proximity effects become of increasing importance and must be studied more carefully than in the past, if exact resistance and reactance values are to be made available, for the multitude of conductor combinations now required by industry. Bar face-to-face spacings of the order of a fraction of an inch are not unlikely.

Assuming a uniform current distribution in each bar, that is neglecting skin and proximity effect, which has been rather common practice, the inductance of a rectangular bus-bar system may be determined from the scientific papers of E. B. Rosa and F. W. Grover.[3,4] This work gives the approximate self inductance of a straight cylindrical wire as:

$$L_s = 2(l)\left(\log_e \frac{2l}{\rho} - 1 + \frac{\mu}{4}\right) \qquad (1)$$

And the approximate mutual inductance between two parallel cylindrical wires as:

$$L_m = 2(l)\left(\log_e \frac{2l}{d} - 1 + \frac{d}{l}\right) \qquad (2)$$

And the approximate net total inductance per wire of a two-wire transmission line as:

$$L = 2(l)\left(\log_e \frac{d}{\rho} + \frac{\mu}{4} - \frac{d}{l}\right) \qquad (3)$$

where

l = length of wire
d = center-to-center separation of wires
ρ = radius of wire
μ = permeability of medium

When the length (l) of the wire is great in comparison with the spacing (d) the last term (d/l) of this equation may be neglected.

For a nonmagnetic cylindrical tube of infinitesimal thickness or for high-frequency circuits, where no magnetic field exists within the conductor then the second last term ($\mu/4$) may also be neglected. This condition is not always met in industrial power distribution practice and the ($\mu/4$) term (with $\mu=1$) should remain in the equation. This term represents the self inductance due to the flux within the conductor itself and is a factor of considerable relative importance on close spacings.

When other than a straight cylindrical wire is employed as for example the rectangular conductor in a busway, it is convenient to use modifying factors to convert the dimensions of the conductor arrangements into that of an equivalent cylindrical wire system in order to utilize the above fundamental inductance relationships.

The most acceptable modifying factors in use at the present are those based upon the concept of geometrical mean distances introduced by Clerk Maxwell.[1] Later F. W. Grover[4] published tables and data for calculating the inductance of rectangular conductors, in which the following definitions appear. "The geometrical mean distance (gmd) of a single area is that distance whose natural logarithm is equal to the average of the natural logarithm of the distances of all points of the area from each other." For a rectangular area of thickness a and width b an approximate expression of self-geometrical mean distance is:

$$R=0.2235(a+b) \tag{4}$$

where R=self-geometrical mean distance.

"The geometrical mean distance of two areas is that distance whose logarithm is the average of the logarithms of the distances of all the points of one area from all the points of the other." If D equals the geometrical mean distance of two areas and d the center-to-center distance between these areas then:

$$D=kd \tag{5}$$

or

$$\log_e D=\log_e k+\log_e d \tag{6}$$

Value of the $\log_e k$ for equal parallel rectangular areas are given in tables by Grover. Doctor O. R. Schurig[13] further simplified the solution of mutual geometrical mean distance by a graph published in his article on the calculation of inductance for rectangular bar conductors.

If the current distribution within each conductor is uniform these geometrical mean distance factors, as discussed by Rosa and Grover, can be substituted in equation 3, R for ρ, and D for d, as follows:

$$L=2(l)\left(\log_e \frac{D}{R}\right)\times 10^{-4} \text{ millihenrys per centimeter} \tag{7}$$

Note that $\mu/4$ turn does not appear in equation 7 since the flux within the conductor is taken into account in the determination of the gmd, and nonmagnetic conductors are assumed. C. C. Levy[13] discussed this point in his article "Calculation of Inductance and Current".

Examples of the geometrical mean distance factors R and D for a range of one-fourth-inch copper bus bars versus conductor spacing are given in figure 1 and figure 2 respectively. Applying these factors to equation 7 the calculated 60-cycle reactance for a wide range of one-fourth-inch bar widths is shown in figure 3. The values in figure 3 are for uniform current distribution.

It is well known, however, that the current distribution within large conductors is not uniform and therefore the geometrical mean distance factor modifications are not strictly accurate. If the current is crowded to the ends and sides of a rectangular conductor due to skin effect and if the crowding effect is made asymmetrical due to proximity effect, then this current distribution pattern is important in the determination of the flux linkages of self and mutual inductance. Further research should be encouraged to determine factors applicable to commercial bus structures, particularly for closely spaced multiple interleaved conductors. It is not only the value of inductance that is important but also the effect upon the current-carrying capacity of the conductors. This will be discussed later in the paper.

Another factor entering into the design of a commercial busway system for a specified voltage regulation is the voltage unbalance between the phases. If the conductor arrangement differs from an equilateral triangle then the individual phase voltages must be calculated and if necessary the phase conductors transposed at intervals along the busway. The problem is often identical to that of a flat transmission line. This unbalance in the induced voltages of the respective conductors is due to two factors: difference in reactance between the respective phases and the 120-degree displacement of the current in the three phases. Fortunately, it is a simple matter to make transposition in most modern busway systems and thereby attain balanced voltages.

In figure 4 are shown phase-voltage readings along an early wide-spaced (five-inch center to center of bars) high reactance, flat facewise configuration busway installation before and after transpositions were made. Present-day closely spaced designs would produce the same relative characteristics, but with voltages of much improved regulation.

Power-factor correction static condensers are often located along the lines of a busway system to take full advantage of improved voltage regulations along with power-factor correction.

In these early systems as well as in many installations of today, reactance plays a dominant part in the impedance drop, while as spacings are made closer, the resistance component becomes increasingly important and may even itself become dominant. Here again, the importance of skin and proximity effect enters into voltage regulation calculations, this time by increasing the a-c resistance.

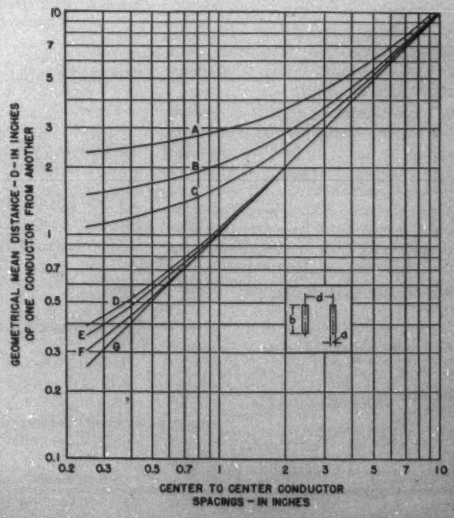


Figure 2. Mutual geometrical mean distance versus spacing for two rectangular bus bars

Designation of bus-bar sizes on curves, all bar dimensions in inches:

A—0.25 by 10
B—0.25 by 6
C—0.25 by 4
D—0.25 by 1
E—0.25 by 0.75
F—0.25 by 0.50
G—0.25 by 0.25

Current-Carrying Capacity

While skin effect causes a higher density in the outside periphery of a conductor, proximity effect has the tendency to crowd the current to the outside when currents flow in the same direction in adjacent conductors and to the inside when currents flow in the opposite direction in adjacent conductors. In certain cases, therefore, proximity effect may in combination with skin effect, actually cause a better distribution of current and, therefore, a lower a-c resistance than results from skin effect alone. On the other hand, these two effects more often combine to produce a considerably greater a-c resistance. Tests have shown this increase in resistance to be very significant. A more comprehensive knowledge of these combined effects will prove beneficial in the accurate establishment of the current ratings of bus-bar systems for a given temperature rise. Limited investigations seem to point to the importance of symmetry where several conductors are connected in parallel.

When bus bars are spaced closely, phases connected in parallel and interleaved as in figure 5, more research and study will be required before an accurate prediction can be made of the system's voltage regulation, power loss, and current-carrying capacity.

It is present commercial practice to rate bus systems arbitrarily on the basis of 1,000 amperes per square inch, despite the fact that this system of rating does not result in a uniform temperature rise for the respective sizes at rated load.

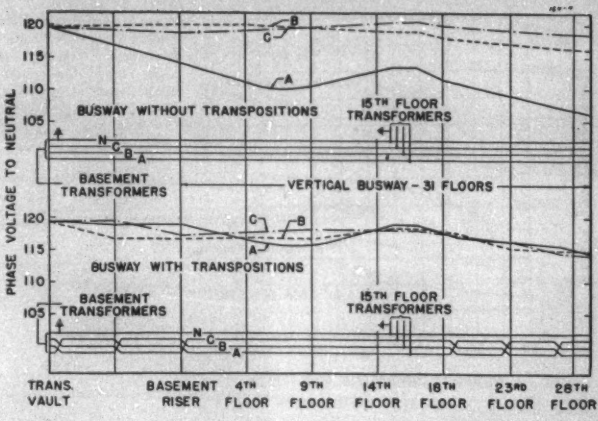


Figure 4. Voltage regulation of the respective phases along a three-phase, four-wire wide-spaced early type busway design before and after making transpositions

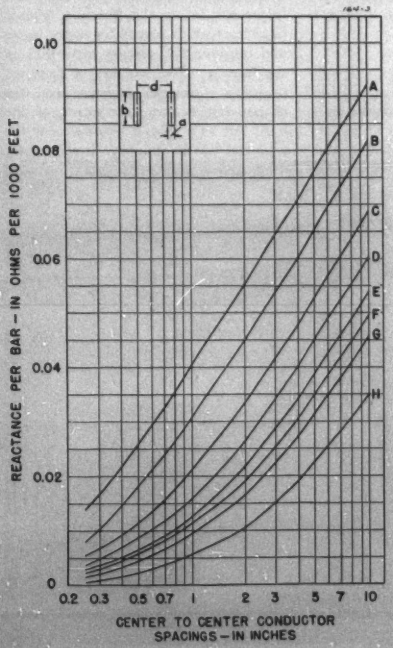


Figure 3. Reactance per bar versus spacing for two rectangular bus bars

Designation of bus-bar sizes on curves, all bar dimensions in inches:

A—0.1875 by 0.625
B—0.25 by 1
C—0.25 by 2
D—0.25 by 3
E—0.25 by 4
F—0.25 by 5
G—0.25 by 6
H—0.25 by 10

Progress is being made, however, toward a more accurate rating of the bus systems through the co-operation of manufacturers with the underwriters. In the meantime, the manufacturers simply provide the necessary capacity to carry the load for the specified temperature rise.

Another and very important factor in the modern busway system is the design of its protective enclosure. The present practice is to make these enclosures of steel for ratings below 1,500 amperes, and of nonmagnetic material for high-current ratings.

Housings of nonmagnetic materials are often preferred to steel for certain high-current rating designs because of the high-flux densities and eddy currents induced in the steel housings which give rise to excessive temperature and voltage drops.

Various means are employed for ventilating the housing and cooling the enclosure by convection, but in general, the enclosed system will not have as high a current-carrying capacity for a given temperature rise as will bars in the open air. Industry, of course, realizes this

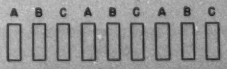


Figure 5. An example of parallel interlaced three-phase rectangular bus-bar conductors

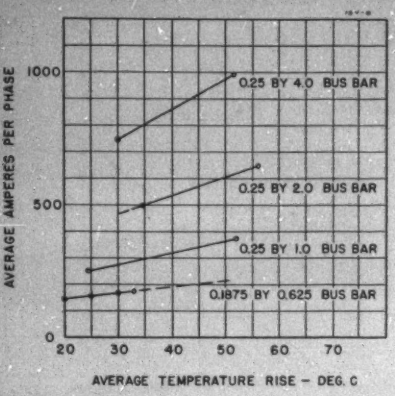


Figure 6. Test data on current versus temperature rise of three-phase, three-bar, 60-cycle plug-in busways. Bus bars of copper. Dimensions in inches

situation and accepts the lower capacity of the enclosed system because of its obvious other advantages. The actual rating of an enclosed system in the final analysis, probably, will be based upon tests of the particular design. In general, it is the same problem as encountered in the operation of a number of cables in a duct enclosure. An example of the carrying capacity of some typical busway systems is shown in figure 6.

Applications

It is interesting that the earliest industrial electrical distribution systems had open feeders extending the length of the plant, with ceiling-mounted link-fuse protection of tapoffs for individual power loads, similar to the fundamental concept of modern busway systems. The fire and personal injury hazards of the materials then available brought about the alternative practice of radiating conduit and wire feeders from a main switchboard or from several subdistribution centers.

The radial system met industry's needs through the early decades of this century, but with the advent of mass production, individual motor drives, expanding and changing load centers, the static nature of the radial system often resulted in overloaded feeders and equipment, poor voltage regulation, and costly rearrangement expenditures. A system which would provide the same convenience for power in industry as plug receptacles do in the modern home, became industry's demand.

Plug-in Busways

This need of industry for a greater convenience of power is being met by manufacturers with a system of power and light plug-in devices which engage bus bars supported within a metal enclosure.

The complete system for an industrial plant usually consists of a number of overhead parallel busway runs located according to machinery concentrations, plant conditions, and column centers. These bus structures are usually located overhead and supported by building structural members. An exception to this method of supporting the busway is shown in figure 10 which is a photograph of an installation in a high bay crane area where suspension means of support could not be used.

Connections are made to the busway circuits by the insertion of combination plug-in switch and protective devices at such points as to provide the most economical branch circuit layout. A section of a typical busway run with plug-in device in position is shown in figure 8. The arrangement of bus bars and construction details of a typical busway type of enclosure with its insulator assembly is shown in figure 7. Branch circuits are extended from the plug-in protective device by the customary wiring method to the individual power equipment drives or distribution centers. Such an example is shown by the photograph in figure 11.

The growing need for the installation of static condensers to correct for low power factor has led to the design of plug-in capacitors which correct for power factor and improve the voltage regulation on the busway. The location of these capacitors, of course, depends upon the characteristics and distribution of the load, but as a rule, a location near the load end of the busway provides best results. A photograph of a typical

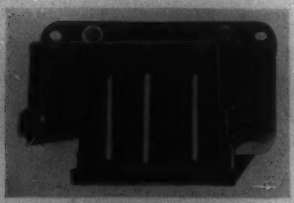


Figure 7. End view commercial design plug-in busway

1/4- by 4-inch rounded edge bars. Insulator one-piece porcelain. Enclosure assembly of formed steel sheets

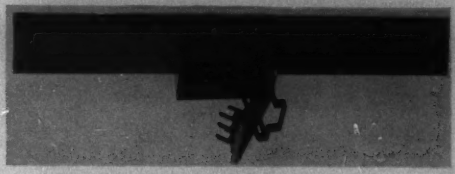


Figure 8. Protective device engaged to plug-in busway through one of the enclosure outlets

Load conduits are extended from knockouts in protective devices

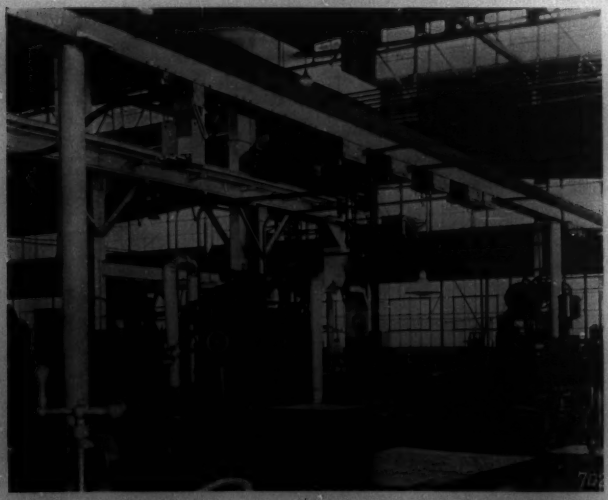
Figure 9. Combination plug-in protective device and capacitor

Figure 10. Plug-in busway system supported by iron pipe uprights spaced on 20-foot centers for supplying power to motors in high bay crane area

plug-in capacitor is shown in figure 9.

The common industrial application of busway plug-in systems is to 440-volt, three-phase, three-wire, 60-cycle a-c power distribution, although there is an increasing acceptance of the plug-in busway for three-phase, four-wire combination light and power systems. Where light is supplied from a busway it is general practice to extend conduit and wire circuits from plug-in equipment to lighting distribution panel boards or transformers. Where there is a need for an even more flexible supply of power to portable tools, such as along an assembly line, it is the practice to install a trolley collecting device supported on a track

Figure 11. A close-up view of layout, figure 10, showing protective devices and branch motor circuits



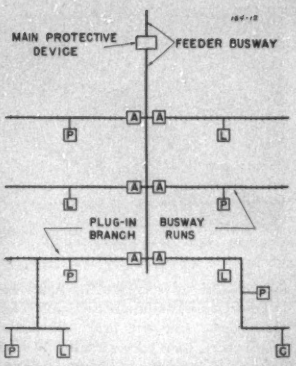


Figure 12. Schematic layout of a busway system frequently used in industrial plants

Symbols indicate protective devices for the following applications:

P—Power loads
L—Light loads
A—Branch plug-in busway
C—Capacitors

which is an integral part of the bus-bar enclosure.

Plug-in busways may be supplied with power directly from distribution centers, by conduit and cable wiring methods, or by a feeder type of busway.

Feeder Busway

Feeder busways differ from the plug-in type in that they are generally of higher current-carrying capacity and are not provided with plug-in outlets. The usual method of tapping off loads from feeder busways is by bus-bar connections or conduit and wire. The conduit and wire branch feeder connections are generally made through metal enclosures attached at the joint sections.

A layout of a typical feeder and plug-in busway system is shown in figure 12. In this figure a section of feeder busway extends from the transformer supply to the main protective device. From the protective device the feeder busway extends the full length of the plant to supply the individual plug-in busway branch runs. Because of the high-capacity requirements of feeder busways it is often necessary to arrange many bus bars in parallel and to interleave the phase conductors to obtain a low reactance. Such a feeder busway is shown by the photograph in figure 13. A multitude of arrangements may result in the application of feeder busways to and from

Figure 13 (left). Commercial design of interlaced feeder busway with steel backplate and ventilated aluminum enclosing channel

switchboard, as is typified by figure 14.

Feeder busway systems, particularly for three-phase, four-wire light and power distribution, have been successfully used as risers in buildings having many floors. The load requirements of each floor are tapped off the busway and distributed through panel boards or plug-in busway.

A comprehensive treatment of the general problem of welding applications as reported by the AIEE subcommittee on power supply for welding applications,[16] is published in the May 1940 issue of ELECTRICAL ENGINEERING. This activity has stimulated the development of feeder busways to provide designs for improved voltage regulation on welder service. These improved designs will be characterized by close phase-to-phase spacing of bus bars and convenient methods of extending conduit and wire feeders from the busway to welding machines.

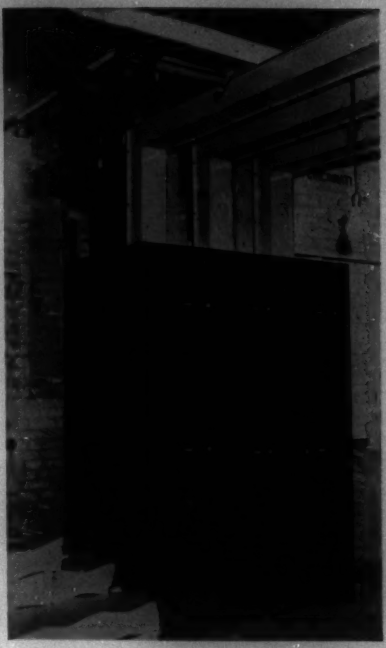


Figure 14. Example of feeder busway extending from a main distribution switchboard

Bibliography

1. ELECTRICITY AND MAGNETISM, Clerk Maxwell. Volume II (1873).

2. ABSOLUTE MEASUREMENTS IN ELECTRICITY AND MAGNETISM, A. Gray. Volume II (1893).

3. ON THE G.M.D. OF RECTANGULAR AREAS AND THE CALCULATION OF SELF-INDUCTANCE, E. B. Ross. Bulletin of the Bureau of Standards, volume 3, 1907.

4. FORMULAS AND TABLES FOR THE CALCULATION OF MUTUAL AND SELF-INDUCTANCE, E. B. Ross and F. W. Grover. Bulletin of the Bureau of Standards, volume 8, 1912.

5. EXPERIMENTAL RESEARCHES ON SKIN EFFECT IN CONDUCTORS, A. E. Kennelly, F. A. Laws, and P. H. Pierce. AIEE TRANSACTIONS, volume 34, 1915, pages 1953–2018.

6. SKIN EFFECT OF A RETURN CIRCUIT OF TWO ADJACENT STRAP CONDUCTORS, H. B. Dwight. *The Electric Journal*, April 1916, page 157.

7. THE REACTANCE OF STRAP CONDUCTORS, H. B. Dwight. *Electrical Review and Western Electrician*, June 1917.

8. SKIN EFFECT IN TUBULAR AND FLAT CONDUCTORS, H. B. Dwight. AIEE TRANSACTIONS, volume 37, 1918, pages 1379–1400.

9. REACTANCE VALUES FOR RECTANGULAR CONDUCTORS, H. B. Dwight. *The Electric Journal*, volume 16, June 1919.

10. UNTERSUCHUNGEN UBER STROMVERDRANGUNG IN RECHTECKIGEM QUERSCHNITTEN, H. Schwenkhagen. *Archiv für Elektrotechnik*, volume 17, January 31, 1927, pages 537–89.

11. CURRENT-CARRYING CAPACITY OF BUSBARS, H. W. Paput. *Electrical World*, September 21, 1929.

12. CALCULATION OF INDUCTANCE AND CURRENT DISTRIBUTION IN LOW-VOLTAGE CONNECTIONS TO ELECTRIC FURNACES, C. C. Levy. AIEE TRANSACTIONS, volume 51, 1932, page 903.

13. ENGINEERING CALCULATION OF INDUCTANCE AND REACTANCE FOR RECTANGULAR BAR CONDUCTORS, O. R. Schurig. *General Electric Review*, May 1933.

14. REACTANCE OF BUSBARS. H. B. Dwight and T. K. Wang. AIEE TRANSACTIONS, volume 57, 1938, pages 762–5.

15. TEMPERATURE RISE OF BUSBARS, H. B. Dwight, G. W. Andrew, and H. W. Tileston, Jr. *General Electric Review*, May 1940.

16. POWER SUPPLY FOR RESISTANCE-WELDING MACHINES, AIEE Subcommittee on Power Supply for Welding Operations. AIEE TRANSACTIONS, volume 59, 1940 (May section), pages 306–20.

Lead Storage Batteries in the Transportation Field

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MEMBER AIEE

Synopsis: A review of storage battery applications in the railroad, motor bus, and aircraft transportation fields. Historical notes are recorded of events in the development of gas and Diesel-electric rail cars and Diesel-electric locomotives, especially as those events relate to storage batteries. Similar treatment is given to other battery applications—car lighting, air conditioning, busses, and aircraft. The changes made in the construction of batteries for these services are described. Physical and electrical characteristics are emphasized where they have a bearing on the application.

Introduction

ELECTRIC starting of automobile engines is taken for granted until you have to crank one by hand. The drivers of 24,000,000 automobiles and 4,000,000 trucks which operate today, have little appreciation of the job done by storage batteries. Probably only those engineers intimately associated with the application of storage batteries in the transportation industry know of the degree to which storage batteries have performed much larger jobs. For example, they are used on all commercial air transports; they furnish the power to crank gas and Diesel engines on over 1,500 rail cars and locomotives, and on over 138,000 busses. Storage batteries also help to electrically air condition over 12,000 railway passenger cars, and they insure power supply to 40,000 signals used by the railroads for safe operation of trains. There are few who are familiar with the changes in design which were necessary to fit storage batteries to the peculiar requirements of certain transportation applications.

I. Railroads

A. Engine Cranking

1. History. At the beginning of the century a self-propelled rail car was introduced in which the electric driving motors received their power from a storage battery operating in parallel with a generator driven by a gasoline engine. The storage battery took care of peak loads and the generator furnished the average power required.

The forerunner of the present-day gas-electric rail car using variable voltage control appeared first in 1905. The engine was started by compressed air. About 1910, a small six-volt storage battery was added to furnish ignition current.

In 1905 a mechanically driven car known as the McKeen car was also introduced. Following Mr. Kettering's success of starting automobile engines by an electric motor in 1911, the idea was expanded to include the larger size gas engines then being applied to rail cars. Usually a 12-volt 120–160 ampere-hour storage battery served for cranking and lighting purposes.

There was a decided lull in the development of rail cars between 1912 and 1924. In the latter year an improved design of gas-electric rail car was introduced in which a 32-volt 215 ampere-hour storage battery was used for engine cranking, car lighting, and generator excitation. Thereafter a rapid expansion in the number of gas-electric rail cars took place. In Europe, on the other hand, gasoline was expensive and difficult to obtain, so that greater efforts were directed toward Diesel-powered rail cars.

In 1923 a Diesel locomotive, employing electric drive, was built in Europe. Starting windings were provided on the generator and the Diesel engine was cranked by the storage battery in this manner for the first time.

In February 1924 a 300-horsepower Diesel electric locomotive was placed in service in the United States. The engine was started by compressed air and a 16-cell 108 ampere-hour storage battery furnished current for excitation, control, and lighting. Two years later a 64-cell battery of the same capacity was added for engine cranking. Soon thereafter the cranking, excitation, control, and lighting circuits were connected to a common 56-cell battery.

In 1933 the Diesel-electric locomotive entered the high-speed passenger train field with a single 600-horsepower engine using a 64-volt 425 ampere-hour battery. Some of the present 6,000-horsepower locomotives are composed of three cab units operated by multiple-unit control. Each cab unit has two 1,000-horsepower engines and a 64-volt 425 ampere-hour battery.

In the early days of electric cranking of engines, it was the practice of locomotive manufacturers to use empirical formulas to determine the torques required to "breakover" and "fire" Diesel engines. By combining this information with the characteristics of the generator starting winding and a battery, it was possible to arrive at a suitable size of storage battery. Experience taught them that a battery sufficiently large to perform the cranking duty would adequately take care of the other electrical duties assigned to the battery. As engines grew larger it was desirable to re-examine the cranking requirements. Oscillograms were obtained of the starting conditions and the information used in a manner similar to that described in a paper delivered before AIEE at its 1940 summer convention in Swampscott, Mass.

2. Adaptation of Storage Batteries. Although the eight-hour battery capacity rating is traditional, it is of little value in Diesel cranking service, because, in this service, the battery must (1) "breakaway" the engine from standstill and (2) quickly bring it up to "firing" speed.

Condition (1) is essentially one of torque, and torque is proportional to amperes. The high breakaway torque has, in practice, required batteries to discharge at rates up to approximately their one-minute rate. To provide the necessary high-current rates, it is desirable to keep the internal resistance of the battery at a minimum and the current-carrying parts of adequate cross section. Condition (2) involves delivery of current for a reduced torque and at a voltage that will give speeds somewhat in excess of the minimum speed required for firing in order that the engine may fire quickly.

In order to satisfy both conditions, it has been found advisable to use multiple current-carrying posts, and to use copper inserts in these terminal posts and in the lead intercell connectors. Also cells were arranged in the trays in such a way as to make the intercell connectors as short as possible and the connectors were lead-burned to the terminal posts in order to reduce contact drop.

Figure 1 shows a typical characteristic of a battery used to crank a 900-horse-

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1. For all numbered references, see list at end of paper.

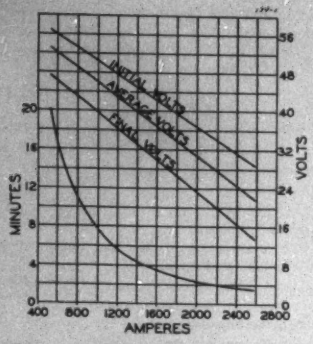

Figure 1. Discharge characteristic of a typical cranking battery

power Diesel engine. Figure 2 shows the accumulated horsepower of Diesel-electric locomotives in the United States.

B. Car Lighting and Air Conditioning

1. History. The first attempts at car lighting by electricity were made in 1881 and continued in an experimental stage for about ten years before practical results were obtained. The Planté type of storage battery which had been developed in 1860 was the first to meet car lighting requirements successfully. The Faure or pasted-plate type of battery was developed about 1881, but was not used in car lighting service until many years later because the earlier designs were not rugged enough. In the early types of car lighting batteries the elements were installed in alloy containers, two containers being grouped in a wooden tray. Porcelain rests supported the elements at a sufficient height from the bottom of the cell to provide space for sediment accumulation. Later, rubber jars were substituted for the alloy containers. In either case alloy or rubber covers were used.

Railroads operated well-equipped battery repair shops and regularly examined car lighting batteries, removing sediment, changing separators, and renewing plates when necessary. It was not uncommon to obtain a life of 20 years from negative plates, requiring three or four sets of positive plates. Gradually this practice of rebuilding batteries was discouraged by the railroads in favor of using a "single life" battery whose separators and plates would wear uniformly. The trend was definitely away from the Planté type and toward the lighter weight pasted-plate type battery.

In 1927 the first air-conditioned railway passenger car, a Pullman sleeping car, was placed in experimental service. Three years later the idea was tried by several railroads, and it was enthusiastically accepted by the traveling public. The rapid expansion of air conditioning on railroads in the United States is shown in figure 3.

Five different types of air-conditioning systems are used by the railroads. They are distinguished chiefly by the manner in which refrigeration is produced, and are separated as (1) ice activated, (2) mechanical compression with the compressor driven by an electric motor (electromechanical), (3) steam ejector, (4) mechanical compression with the compressor driven directly from car axle (direct mechanical), and (5) mechanical compression with the compressor driven by an internal combustion engine. The refrigeration capacities available for railway passenger cars vary from three to nine tons per 24 hours.

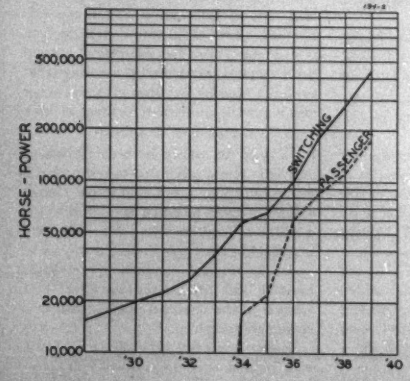

Figure 2. Cumulative horsepower of Diesel-electric locomotives in U.S.A.

Before describing the increased power requirements brought about by the addition of air conditioning, it will be helpful to refer to table I which shows what the Association of American Railroads set as a standard for storage battery and generator capacities when applied to *car lighting* service. The AAR is undertaking a study to make comparable recommendations for combined air conditioning and car lighting service. During the past three years better illumination has been emphasized and has been adopted in varying degrees by different railroads. Attractive interiors were provided on newly designed cars with new and improved types of lighting fixtures which meant further increases in intensity at the lighting source. In some of the latest cars the lighting load has reached a total of 170 amperes at 32 volts.

These heavier lighting loads plus any additional amount demanded by air-conditioning equipment are taken from the storage battery during periods of a train run when the train is operating below the cut-in speed of the generator and, in some cases, when the car is being precooled prior to a run. This was responsible for increasing the size of the storage battery to from two to four times that previously used in car lighting service alone. The capacity of generators was also increased to correspond with the increase in load. Experience indicates that a minimum generator capacity of 166 per cent of the connected load should be provided. While this ratio may seem somewhat high for new cars in long runs or express service, it is only a matter of time when such new cars are relegated to local or semilocal service in which higher generating capacity is desirable.

2. Air-Conditioning Power Requirements. The electric load in an ice activated system consists of 0.5 kw to the cooling coil fan and 0.75 kw to the cold water circulating pump or a total of approximately 38 amperes at 32 volts. In the majority of cases, one four-kilowatt axle-driven generator has sufficed. Referring to table II, it will be noted that the 600 ampere-hour size battery is the most popular. However, the lighting load and the type of car has influenced the choice of this capacity more than has the air-conditioning load.

The greatest range in power requirements occurs in the electromechanical system of air conditioning. Refrigeration capacities vary from 3.5 to 9.6 tons. In the vicinity of the six-ton rating, the total power requirements may vary from 8.5 kw to 12 kw. The motor driving the compressor requires approximately 93

per cent of this total, the remainder being consumed by evaporator fans, control, and in some cases, condenser fans. Comparisons made of various manufacturers' equipment rated around six tons showed that an average of 1.75 kw per ton of refrigeration was required, or a total of 10.5 kw at six tons. This represents an average increase above car lighting requirements of about 330 amperes at 32 volts. Generator capacities were raised to 15 kw, then to 20 kw, but it was not practical to increase the storage battery capacity correspondingly. Space and weight are limited and the problem became one of how much capacity could be installed in the standard AAR battery box. The electromechanical system of air conditioning imposed the greatest demands on the storage battery and therefore provided the greatest influence in the change of storage battery design. One of the large eastern railroads, a pioneer in the use of the electromechanical system, set 1,000 ampere-hours capacity (32 volts) of storage battery as a goal for manufacturers to strive to build and install within the standard compartment.

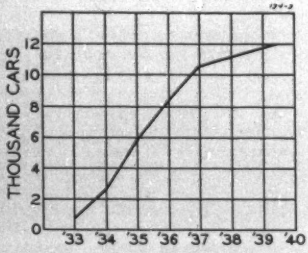

Figure 3. Air-conditioned railway passenger cars in U.S.A.

The power required in the steam ejector system is second to that of the electromechanical system. The total load amounts to approximately 104 amperes at 32 volts and consists of the condenser fan, condenser pump, cooling coil fan, and cold water pump. Referring to table II, it will be noted that the majority of installations use approximately 850 ampere-hour storage batteries. Generator capacities for this type of system vary from 7½ kw to 10 kw, the latter size being found in most cases.

The direct mechanical system has the lowest electrical requirement and therefore the least effect on the size of battery installed. The 550 ampere-hour capacity was the most popular because one of the largest operators of air-conditioned cars chose it as their standard. It is estimated that the bulk of installations from 1938 to date used 600 ampere-hour batteries.

One manufacturer has developed an internal combustion engine which uses bottled propane for fuel and can be adapted to drive either a compressor or a generator. As an engine generator it removes the load from the car axle and there is no change in electric power used. When the engine is directly connected to the compressor, however, the electric power requirements drop to that of the direct mechanical system. Most of the installations of this type of system have been made on railroads in the Middle West and the preponderance of 450 ampere-hour storage batteries coincide with the standard size of car lighting battery of two large users.

3. Storage Battery Developments. The life of Faure or pasted plates depends on the cohesion of the active material and its retention by the grid structure. These are influenced by the porosity of the active material and by the shape of the grid section. Thus a soft porous plate will give higher capacity in its early life, but has a tendency to shed the active material. Hard dense plates do not give as much capacity initially, but are slower to "soften" with work and age, and consequently will give much longer life. It is of prime importance that plates be uniform because they will be "teamed" as groups in a battery which must work and wear evenly. To accomplish uniformity manufacturers must control closely not only the quality of materials used but also the physical conditions of manufacture, such as temperature, time and humidity, that exist while making and processing the plates.

A retainer or envelope is placed about the positive plate for a twofold purpose: (1) to hold the oxides in place mechanically and in contact with the grid, and (2) to delay oxidation of the separators. In one case the retainer has been a thin sheet of finely slotted rubber. In another case a modified Faure plate was made by enveloping a series of grid pencils with cylinders of active paste material and each cylinder encased in a finely slotted rubber tube. In a third case the retainer has been a thin mat of fibrous material usually made of spun glass.

Plate separators act as electrolytic diaphragms which permit current to pass freely between the plates but prevent any migration of dislodged active material from one plate to another of opposite polarity which might bridge and cause a short circuit. In some respects wood is an excellent material for separator use but its disadvantage lies in its inability to withstand high temperatures. In 1933 a new separator was developed from liquid latex, or the milk of rubber as the base. This material when compounded with certain other materials and vulcanized forms a microporous diaphragm which successfully withstands oxidation and heat. In another case a similar separator was obtained by vulcanizing a mixture of crude rubber and sulfur with certain other materials, the latter being dissolved out to form the minute pores.

The trays used for car lighting batteries were usually made from oak, maple, or long-leaf yellow pinewood, painted with an asphaltum paint and then immersed in a molten wax compound. Hard rubber jars held the elements and electrolyte, and the wood trays became the supporting structure for two or more jars. Such an assembly occupied more space and weighed more than a self-supporting container. Another disadvantage occurred when high temperatures melted the wax coating and exposed the wood to decay. A self-supporting rubber monobloc container was developed in 1935. This container saves space, is not subject to decay, and possesses a remarkable quality of toughness. It is handmade from rubber compounds which contain relatively high percentages of rubber. One type of container is made up of two dissimilar rubber compounds—one resistant to heat, the other resistant to shock—calendered together and handwrapped about mandrels, and then vulcanized. There are now over 50,000 of these monobloc containers in service.

Table I. AAR Recommended Battery and Generator Capacities for Railway Car Lighting

Class of Service	Amperes Load	Battery Capacity Range Ampere-Hours Min	Max	Generator Capacity (Kw)
Official, sleeping, parlor, mail, and dining cars having heavy lighting loads or severe operating conditions	50	350	600	4
Mail, dining cars, etc., where the lighting loads are not so heavy or the operating conditions so severe	35	300	350	3
Coaches, passenger-baggage cars, baggage cars under average operating conditions	25	200	300	2
Same cars as next above operating in slow speed branch line or local service	25	150	225	2

Table II. Storage Battery Installations in Air-Conditioning Service

Air-Conditioning System	Ampere-Hour Capacity Range		Electrical System (Volts)	Installations Made in						Nine-Year Summary	
				1933*	1934	1935	1936	1937	1938	Total	Per Cent
Ice											
		300	110	0	0	0	3	3	0	6	0.2
	250	350	32	6	29	35	29	44	0	143	4.1
	375	450	32	25	50	314	360	31	1	781	22.5
		500	32	108	101	112	146	34	3	504	14.5
		600	32	97	538	511	594	165	13	1,918	55.1
	750	900	32	55	15	25	9	5	2	111	3.2
	1,000	1,200	32	6	2	0	0	4	0	12	0.4
	Total			297	735	997	1,141	286	19	3,475	31
Compressor driven from an electric motor											
		300	110	0	7	30	47	26	5	115	5.4
		450	64	0	11	7	0	0	0	18	0.8
		500	64	0	0	60	50	75	50	235	11.1
		600	64	0	6	57	62	104	8	237	11.2
	750	800	32	10	33	20	16	0	0	79	3.8
	900	1,000	32	188	292	486	174	282	3	1,425	67.2
	1,200	1,250	32	0	0	4	0	0	2	6	0.2
		2,000	32	3	3	0	1	0	0	7	0.3
	Total			201	352	664	350	487	68	2,122	19
Steam ejector											
	550	600	32	2	20	57	78	31	109	297	15.6
	700	800	32	3	37	35	72	40	6	193	10.2
	850	875	32	0	132	407	145	327	152	1,163	61.2
	900	950	32	33	2	10	12	72	1	130	6.8
		1,000	32	5	6	28	14	35	20	108	5.7
		1,200	32	0	0	0	0	10	0	10	0.5
	Total			43	197	537	321	515	288	1,901	17
Compressor driven mechanically from car axle											
	300	350	32	0	6	118	9	30	4	167	5.0
	375	450	32	33	74	17	74	88	0	286	8.5
		450	64	0	4	0	0	0	0	4	0.1
		500	32	12	19	61	30	75	0	197	5.9
		550	32	0	395	882	505	363	54	2,199	65.9
		600	32	61	1	4	14	91	62	233	6.9
		600	64	0	32	0	0	0	0	32	1.0
	800	900	32	0	0	21	3	63	63	150	4.5
		1,000	32	0	62	2	0	3	0	67	2.1
		1,250	32	0	0	0	0	0	2	2	0.1
		1,800	32	0	0	1	0	0	0	1	
	Total			106	593	1,106	635	713	185	3,338	30
Compressor driven from internal combustion engine											
	200	400	32	0	0	1	1	36	11	49	15.4
	450	600	32	1	0	3	57	146	29	236	74.3
	750	850	32	0	1	13	0	8	0	22	6.9
	900	1,000	32	0	0	1	3	6	1	11	3.4
	Total			1	1	18	61	196	41	318	3
Grand total				648	1,878	3,322	2,508	2,197	601	11,154	100

*This also includes all installations made prior to 1933.

In order to minimize IR drop, number 0000 cable composed of upward of 5,000 strands of wire is used to connect adjacent battery trays where 800 to 1,000 ampere-hour batteries are used. Extra flexible cable is required for the larger batteries which practically fill available compartment space. One alternative for reducing the large cable requirement has been adopted by several railroads when the system voltage was doubled to 64- and 32-cell 500 ampere-hour or 600 ampere-hour storage batteries used. In another case one railroad equipped 115 cars with 110-volt lighting and air-conditioning systems.

Table III compares a 300 ampere-hour Planté car lighting battery of 1920 with a typical car lighting battery as used today. Today the railroad can obtain a 300 ampere-hour car lighting battery that will occupy one-third the volume of the 300 ampere-hour Planté battery used in 1920; it will weigh only 40 per cent of the 1920 battery; it will cost only 70 per cent as much, and will have a longer life expectancy.

For heavy duty air-conditioning service, it is now possible to install a 16-cell 1,000 ampere-hour battery in the same size compartment which formerly held 16 cells of a 400 to 450 ampere-hour battery. The increased cycling of the battery together with the heavier loads mean higher operating temperatures which are now permissible because of the present development of plate separators. Tightly packed elements permit today's storage batteries to operate throughout their life without mechanical failure of the separators which otherwise might be caused by vibration. Compared with the 1920 300 ampere-hour car lighting battery, the railroad can obtain today an air-conditioning battery of $3^1/_2$ times the capacity installed in the same size compartment, weighing only 25 per cent more, costing only 70 per cent more, and, when used on a load ten times greater, having a life expectancy equal to the 1920 battery.

C. Street Railway PCC Cars

Several papers have been presented to the Institute on "Presidents Conference Committee" street railway cars. Today there are about 1,500 of these PCC cars in service in this country, each of which is equipped with a 16-cell 55 ampere-hour storage battery. The battery is connected across a voltage-regulated motor-generator set. The loads on the battery circuit include magnetic track brakes, control, step treadle equipment, headlight, stop lights, marker lights, passenger signal system, instrument panel, and sometimes fare box lighting. The total load may reach a maximum of 75 to 80 amperes while magnetic track brakes are energized.

II. Motor Busses

Passenger busses are classified along with passenger automobiles and trucks as automotive equipment. While technical discussions on this subject are nor-

mally conducted by SAE, a few remarks on the application of storage batteries to busses may be appropriate in view of their widespread use for commercial transportation.

The year 1911 marked an important milestone in the development of automotive equipment, for it was in that year the electric starting motor for gasoline engines was introduced. Prior to that time all automotive engines were cranked by hand. A campaign for better illumination of bus interiors brought greater lighting loads and in order to minimize voltage drop, a 12-volt circuit was standardized. Battery sizes increased with the change in lighting load from 13 plates to 17 plates and in some cases up to 25 plates. Bus battery plates were thicker than those used in automobile batteries because busses operated in more continuous service and under more adverse conditions.

In railway, marine, and stationary battery applications it is customary to rate the batteries on an eight-hour basis, whereas in bus service it is customary to rate them on the four-hour basis. The capacity of bus batteries was at one time selected on the basis of a six-hour reserve for the operating load exclusive of the starting motor. From experience it was found that a size capable of supplying this reserve was ample for any starting conditions normally encountered. Today the electric loads on busses reach values of 65 amperes at 12 volts and the size of battery recommended is one that will carry the load for four hours.

Fuel economies associated with Diesel engine operation helped to bring about the development of the small high-speed Diesel for bus and truck service. Two six-cell bus-type batteries are connected in series for 24-volt starting and then paralleled for 12-volt lighting.

In 1935, trolley busses made their appearance with 12-volt storage batteries used for control and lighting purposes to avoid high trolley voltages within the bus.

III. Aircraft

Military planes have been responsible for most developments of aircraft electric equipment. The Liberty motor in service during World War I was the first to use a storage battery for ignition. The battery weighed 11 pounds and contained four cells with seven plates per cell.

By the end of that war, military planes were being equipped with direct drive starters. The cranking batteries were usually six-cell, 20, 35, or 70 ampere-hours capacity (five-hour rating). Similar equipment was used by mail and commercial planes about 1925.

The inertia starter, brought out in 1925 plus an improved design of generator, hastened the adoption of electric starting of aircraft engines. Because of the importance of weight, very thin pasted-plate batteries were developed for aircraft service. The plates used in the first Army plane batteries were only 0.05 inch thick. As airplane flights became longer, swifter, and more severe on auxiliary equipment, it was found desirable in 1930 to increase the plate thickness by 50 per cent.

Table III. Comparison of 1920 and 1940 Typical Car Lighting Batteries

	1920	1940
8-hour capacity	300 A.H.	300 A.H.
No. cells per tray	2	4
Tray material	Wood	Rubber monobloc
Tray dimensions		
Length	24 1/4"	19
Width	11"	9 1/4"
Height	19 1/4"	19 1/4"
No. trays per battery	8	4
Total battery volume	24.26 cu. ft.	8.5 cu. ft.
Total battery weight	2,600 pounds	1,010 pounds
Purchase price	100%	70%
Expected life	5 years	7 years

It is interesting to note that a modern passenger airplane's intermittent load on a 12-volt circuit may total 225 amperes. During a 5 1/4-hour night flight in the winter, a typical example of the electric load would be about 490 ampere-hours at 12 volts normally supplied by two 50-ampere generators in parallel. The six-cell 13-plate battery used in this example weighs 78 pounds, has a capacity of 88 ampere-hours (five-hour), and occupies a space 14 by 7 by 11 inches high. It would be capable of carrying 150 amperes for 18 minutes or 200 amperes for 12 minutes.

The large 21-passenger skyliners have two 850-horsepower engines, two storage batteries like the one described above, and means to use either battery or both connected in parallel. The latest Stratoliners have four 1,150-horsepower engines and two 24-volt 50 ampere-hour batteries. The very large engines are using the direct drive starter again rather than the inertia starter. To conserve battery capacity, the heavy duty cranking prior to a plane's departure from an airport, is taken care of by a portable ground-cranking battery which is wheeled under the plane.

Future Developments

Thought and study is being devoted to heating railway passenger cars electrically. Air conditioning includes the proper control of temperature and humidity of the air during winter months as well as summer months. At least three manufacturers are now developing engine-driven equipment that will heat, light, and air condition a car. On one system it is planned to generate 220 volts three-phase, alternating current for heating and air-conditioning purposes. A 64-volt 150 ampere-hour battery will be used to crank the engine, provide the control circuit energy, and light the car. The battery will be charged from the exciter. The adoption of 64 volts direct current for lighting permits the use of a recent development—the fluorescent tube which operates at 60 volts direct current from the battery circuit without transformation of energy. Thus the engine may be shut down temporarily without affecting the source of illuminating power.

In view of the large quantities of rubber materials now used in the production of lead storage batteries, some concern is felt for the continuity of crude rubber supplies. While numerous synthetic rubber substitutes are now being marketed, little enthusiasm can be expressed for any one of them at this time, because experience has taught us to be wary of any possible unhappy union of storage battery electrolyte with an element from the synthetic material. Research is now directed toward the use of some of the newly developed plastics, and it is predicted that they will find increased use in the storage battery industry.

References

1. The Gas Electric Car—Characteristics and Operating Features, L. C. Josephs, Jr. *Proceedings* of Association of Railway Electrical Engineers, October 1931, page 237.

2. Self-Propelled Railway Passenger Cars, S. T. Dodd. *General Electric Review*, 1913, page 637.

3. Engineering Report on Air Conditioning of Railroad Passenger Cars, prepared by Division of Equipment Research, Association of American Railroads, April 15, 1937.

4. Statistics on Generator and Storage Battery Capacities Used on Air Conditioned Cars obtained from the following issues of *Railway Electrical Engineer:* February 1934; December 1934; March 1936; February 1937; February 1938; April 1939.

5. Investigation of Starting Requirements of a 660 Horsepower Locomotive Diesel Engine, J. C. Davidson and R. Lamborn. AIEE Transactions, volume 60, 1941 (January section), pages 31-4.

Bushing and Associated Insulation Testing by the Power-Factor Method

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I. Introduction

THE periodic cleaning, inspection, and testing of equipment plays a very important part in obtaining service continuity. The cost of the labor and equipment involved in locating and eliminating defective apparatus by the above procedure may well be charged to that hypothetical account known as "preventive maintenance." The economics of the procedure, however, must be governed by the results obtained.

For many years, bushings and associated insulation such as the internal parts of circuit breakers and windings of instrument and power transformers were tested by methods which were frequently unreliable, inadequate or of a destructive nature. During the past ten years the a-c test known as the power-factor method of insulation testing has gradually been replacing the former methods used for periodic checkup. It is also gaining recognition as one of the requirements in the acceptance tests made on certain types of new equipment.

The results obtained by Philadelphia Electric Company, using the power-factor test method for approximately eight years, has warranted the continuation of a periodic test program. A few bushing failures still occur but they are confined mostly to the low-impulse type of design and cannot be anticipated by any nondestructive type of test. A centralized bushing repair shop has provided the means for salvaging bushings and other equipment at a reasonable cost, for years of useful life. All equipment rejected by test has, upon investigation, disclosed faulty insulation which warranted its removal from service.

II. Scope of Testing

The power-factor method of insulation testing was first used by this company in 1933, and was confined primarily to outdoor oil circuit breaker bushings. The Doble type *I* tester was used for this work and the results of the first three years' work has been previously summarized.[1]

In 1936, a second type *I* tester was placed in service and the range of testing was broadened to include power and instrument transformers and lightning arresters. With the further development of test equipment by the Doble Company, the two type *I* sets were replaced in 1939, by an *I*-10 and an *I*-30-150 set. A type *U* set was also obtained for use in the bushing repair shop in 1938.

The power-factor testing outlined for each year is as follows:

(*a*). Outdoor oil circuit breakers.

(*b*). Power transformers.

(*c*). Instrument transformers, alternated every other year with station-type lightning arresters.

(*d*). Cold collar and/or hot collar tests on all bushings containing a compound filler.

(*e*). Hot-guard test on all draw-lead type transformer bushings.

(*f*). Oil samples on all power transformers.

(*g*). Oil samples on all oil circuit breakers and instrument transformers as necessitated by over-all test results.

(*h*). Spare bushings.

(*i*). Follow-up field tests as required.

(*j*). Indoor oil circuit breakers during winter months.

(*k*). Follow-up and acceptance tests on all equipment reconditioned in the shop (by the shop force).

(*l*). Acceptance tests on all new bushings.

(*m*). Base checks on all new power transformers.

III. Field Testing

The technique of field testing has been very thoroughly covered in previously published articles,[2–7] listed in the bibliography and will, therefore, not be repeated.

It requires about two years' work to completely cover the outdoor equipment on the Philadelphia Electric Company system. However, the most important locations are tested yearly. A tentative schedule allocating the work is made up each year as a guide for the field test men. Due to its larger capacity, the *I*-30-150 set is used for practically all power transformer tests.

In order to insure proper follow-up of rejected equipment, a 3- by 5-inch card is used for each piece of equipment tested (bushings are included with the circuit breaker) and the condition of the equipment is noted as satisfactory, follow-up, or rejected. These cards are sent daily to the superintendent in charge of the location where the testing is being done. A summary sheet of all rejected equipment is made up weekly and forwarded to the general superintendent of the respective division. When the testing at a specific location has been completed, a copy of each data sheet, approved by the supervisor in charge of the tests, is forwarded to the superintendent of that location for reference and file.

Field testing is seldom carried on when the ambient temperature is lower than five degrees centigrade or when the humidity is high enough to cause considerable surface leakage. The rating schedule for bushings and instrument transformers at 20 degrees centigrade ambient temperature is given in table I.

An arbitrary value of five per cent maximum at 40 degrees centigrade has been established for power transformers although it is still a moot question as to the satisfactory condition of the winding insulation when lower than one per cent especially when subjected to a dry-out run. The current and watts loss readings must also be carefully analyzed and due consideration given to the type of insulation and winding construction before the unit is accepted or rejected.

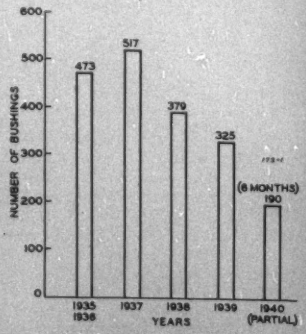

Figure 1. Bushings reconditioned in the shop. Total for 5 1/2 years = 1,884

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1. For all numbered references, see list at end of paper.

Considerable work has been done since 1937, in the investigation of station-type lightning arresters such as the oxide film, type *BO;* auto-valve, type *SV* (disk and porous block construction); and Thyrite, types *LAIB* and *LAIY*. Arbitrary values obtained by comparison and internal investigation of units are being used rather successfully but it is hoped that compilation of further data will offer a more direct solution of the problem.

Wood members, insulators, and the porcelain-tube type of wall bushings are analyzed on the basis of current and watts loss data rather than by power factor. Satisfactory oil is found to be one per cent or under. Above that value other tests, such as dielectric, acidity, color, etc., are made before rejection.

IV. Test Results

A. Bushings (Field Test)

For the three-year period 1933–35 inclusive, about 6,000 bushings were tested. Since that time approximately 4,000 bushings are tested in the field each year. Table II indicates that 1,493 bushings of various types and voltages have been rejected in the past five years. This represents about 7.5 per cent of the total number tested. It should be noted that the rejection of indoor bushings during the past four years accounts for approximately 30 per cent of the total number rejected. The rating schedule was arbitrarily lowered for the indoor bushings on the basis that they would only be tested at four- or five-year intervals.

Table III presents a breakdown of the reasons for rejection. Power factor accounts for 65 per cent of the total and compares with the results of the 1933–35 period[1] of 63.8 per cent. However, in order to make a fair comparison, the indoor bushings must be deducted which would then approximate 35 per cent instead of 65 per cent. This indicates that the trend is downward which should be expected in order to justify the expenditures made in replacement and reconditioning. Moisture accounts for more than 90 per cent of the rejections by power factor.

The 17 per cent rejection due to oil migration and compound leaks is confined largely to transformer bushings and is usually determined by inspection rather than test. The "miscellaneous rejections" is somewhat high (14 per cent) due to placing a number of multipiece porcelain bushings which were rebuilt with single-piece porcelain, in this classification. The percentage of miscellaneous rejections would be in the order of three per cent or less if this modernization item were omitted.

Figure 2. Bushing reconditioning report

BUSHING RECONDITIONING REPORT

Shop No. _____ 172-2

Date Received _____ Date Completed _____

Mfg.	Kv.	Amps.	Station	Date Removed
Type	Form		Equipment	Reason for Removal
Dwg. No.	Ser. No.		Porcelain / Core / Static Shield / Date of Mfg.	
			Top Assembly / Flange / Gaskets	
			Test Set Used / High Pot. Test Voltage Kv. / Date	

Repair Cost Data

Material

Labor

Total Cost

Compound

Notes for Reassembly

TRANSFORMER DATA

Resistance	As Received	As Completed
Primary to Ground		
Secondary to Ground		
Primary		
Secondary		
Primary to Secondary		

Date	In	Ma.	Wa.	P.F.	°C.	Date	In	Ma.	Wa.	P.F.	°C.

Remarks

Repaired by _____ Shipped to _____ Date shipped _____

Installed _____ Date _____ In _____ Bus _____ ϕ _____ S _____

B. Bushings (Shop Test)

The bushing reconditioning shop was started in 1935. Figure 1 shows the number of bushings reconditioned since that time. The total of 1,884 consists of all types of bushings ranging from 7.5 kv to 73 kv. The first year was devoted to the training of personnel, experimentation with materials and methods, building special racks, providing special tools, etc. Larger ovens were designed and installed in 1936, so that large-scale production did not get under way until 1937. During the period 1935–37, it was necessary to assign a field man for shop testing several days each week. This decreased the amount of outdoor testing possible and at the same time proved to be inadequate to meet shop requirements. In 1938, a Doble type *U* set was provided. The shop men now average about 3,000 tests (follow-up, acceptance, etc.) per year.

All bushings (15 kv to 73 kv) after being reconditioned are subjected to a one-minute hold voltage test using the values recommended by the manufacturer for present-day design. This test has resulted in the elimination of a few older type bushings which probably would have failed in service due to faults which could not be determined by a nondestructive test.

Figure 2 is the form developed for detailing the shop history of bushings and instrument transformers. Figures 3 and 4 show the front and rear view of the type *U* tester used in the shop.

C. Transformers

During the past four years, 493 power transformers have been tested. This group of transformers covered a voltage range from 13.2/2.3 kv to 220/66/13.2 kv and a capacity range of 100 kva to 43,333 kva single phase and 1,000 kva to 20,000 kva three phase. All low-voltage windings (2.3 kv and 4 kv) are tested at 5 kv, the higher voltage windings at 10 kv. From the test data obtained, the transformers have been divided into three groups as follows:

Per cent power factor at 40 degrees centigrade: under 5.0, 274; 5.1 to 10.0, 136; over 10, 83.

This grouping is used as a follow-up in

Figure 3. Front view of type U tester used in reconditioning shop

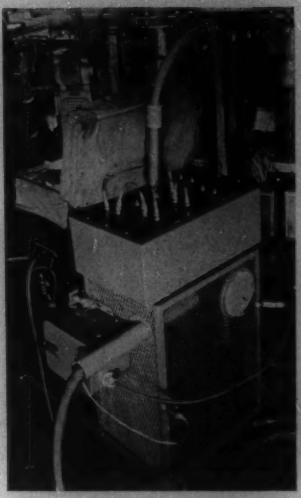

Figure 4. Rear view of type U tester used in reconditioning shop

order to determine the trend of deterioration in the various units of a group from year to year.

Table IV shows the results obtained in drying out seven units in 1937. In all cases, the windings were removed from the tanks and dried out by the hot air method at 85 degrees centigrade. Subsequent tests to date on these transformers have shown that the "as left" readings have remained stabilized. The bushings were reconditioned in the shop and are included in both the "as found" and "as left" readings. Moisture was the contributing factor to the high pow · in each case.

Instrument transformers and metering units rejected during the past five years are listed in table V. These units were reconditioned in the shop and again moisture was found to be the major cause for rejection.

D. Miscellaneous

Several hundred defective supporting insulators have been removed from service either as a direct result of being found by test or by the inspection of equipment by the field test man.

Wood cross braces, *A* frames, lift rods, etc., have been reconditioned due to field investigation and rejection.

Power-factor test on oil samples is used as one of the criteria for recommending reconditioning.

Testing of lightning arrester units by power factor has resulted in the reconditioning of several hundred units due to

Table I A. Bushing Power-Factor Rating Schedule

Bushing Condition	Per Cent Power-Factor Limits for Various Type Bushings at 20 Degrees Centigrade				
	Kv	Condenser	Oil-Filled	Compound	Porcelain*
Satisfactory	15–37	0–3.0	0–3.5	0–3.5	0–3.5
Satisfactory	73–230	0–2.0	0–2.0	0–2.5	0–3.5
Follow-up	15–37	3.0–5.0	3.5–5.0	3.5–5.0	3.5–6.0
Follow-up	73–230	2.0–3.0	2.0–3.0	2.5–4.0	3.5–5.0
Replace	15–37	Over 5.0	Over 5.0	Over 5.0	Over 6.0
Replace	73–230	Over 3.0	Over 3.0	Over 4.0	Over 5.0

* Current and watts readings are of more value than power factor for this type of bushing.

Application of the above values may be somewhat arbitrary based on type of bushing construction, service requirements, and analysis experience. Approximately eight years of use has proved their reliability.

Table I B. Instrument Transformer Power-Factor Rating Schedule

Type P.T.	Per Cent Power-Factor Limits at 20 Degrees Centigrade			Type C.T.	Per Cent Power-Factor Limits at 20 Degrees Centigrade		
	Satisfactory	Follow-Up	Replace		Satisfactory	Follow-Up	Replace
E-15	5.0	5.0–7.0	Over 7.0	*K*-31	3.0	3.0–5.0	Over 5.0
E-115	5.0	5.0–7.0	Over 7.0	*K*-32	4.0	4.0–6.0	Over 6.0
E-16	3.5	3.5–5.0	Over 5.0	*K*-61	3.0	3.0–5.0	Over 5.0
E-116	3.5	3.5–5.0	Over 5.0	*K*-204	2.5	2.5–4.0	Over 4.0
P	3.5	3.5–5.0	Over 5.0	*OA*	4.0	4.0–6.0	Over 6.0
(34.5 kv) *VC*	3.5	3.5–5.0	Over 5.0	*O*-37	3.0	3.0–5.0	Over 5.0
(73 kv) *VC*	2.5	2.5–4.0	Over 4.0	*KE* (meter unit)	2.5	2.5–4.0	Over 4.0

broken castings, defective seals, corroded internal parts, etc.

V. Bushing Failures

Moisture was responsible for 69 per cent of the 48 bushing failures occurring between 1932 and 1940, as shown in figure 5. Entrance to the bushing was gained in most cases through defective gaskets or cement seals. In 1935, 12 of the 15 failures were caused by defective gaskets. This led to the program of replacing the top gaskets on nearly 1,000 bushings in place as previously reported.[1] Of the total failures (48), 27 per cent had never been tested and 6 per cent had been recommended for replacement previous to failure. The type *SI* compound-filled bushing was involved in 69 per cent of the failures with the condenser type accounting for 23 per cent. While it is not expected that failures will be eliminated entirely, it is definitely realized from the experience gained during the past eight years that many incipient failures were removed from the system.

Very few follow-up tests are made since the reconditioning shop was established. A bushing is now recommended for reconditioning if it does not pass the "satisfactory" rating. This eliminates the possibility of a failure between tests because the rate of deterioration is an unknown factor and also provides more time for productive effort on that equipment yet to be tested.

VI. Conclusions

From the experience gained and the data compiled in eight years of testing and reconditioning, the following conclusions may be logically presented:

1. The power-factor test has provided an adequate nondestructive method for determining insulation deterioration.

2. It is satisfactory in the results obtained and therefore justifies its continuation.

3. Due to the unknown factor "rate of deterioration" the period for testing of equipment at important locations should not exceed one year.

4. The major factor in insulation deterioration is moisture.

5. The rating schedules used for various types of equipment have proved satis-

Table II. Number of Bushings Rejected (1936 to 1940)

		Condenser	Oil-Filled	(SI) Compound	Porcelain	Total
1936	O.C.B.	119*	1	130	4	254
	trans.	38†	6	142	24†	210
1937	O.C.B. (outdoor)	35	33**	32	7	107
	O.C.B. (indoor)	32			1	33
	trans.	3		70	4	77
1938	O.C.B. (outdoor)	52		108	1	161
	O.C.B. (indoor)	252				252
	trans.	2		39	32	73
1939	O.C.B. (outdoor)	10	2	24		36
	O.C.B. (indoor)	156		5		161
	trans.	1	1	26	7	35
1940 (partial)	O.C.B.	8	2	57		67
	trans.	7		12	8	27
Total		715	45	645	88	1,493
Per cent of total rejected		48	3	43	6	

*Includes a change from multipiece to single-piece porcelain.

**Includes a rebuild of 24 obsolete type bushings.

†Includes 10 condenser and 18 porcelain bushings damaged by fire.

Table III. Reasons for Rejection (1936 to 1940)

	Power Factor	Oil Migration and Compound Leaks	Broken Porcelain	Miscellaneous*	Total
1936	286	86	43	49	464
1937 outdoor	113	55	9	7	184
1937 indoor	32		1		33
1938 outdoor	79	53	3	99	234
1938 indoor	252				252
1939 outdoor	26	22	2	21	71
1939 indoor	156	5			161
1940 (partial)	25	34	4	31	94
Total	969	255	62	207	1,493
Per cent of total rejected	65	17	4	14	

*Includes voids, low compound level, defective cement and litharge seals, defective gaskets, carbonized compound, certain modernization, etc.

Table IV. Results Obtained in Drying Out Seven Power Transformers, Oil Conservator Type

Case Number		Kva	Voltage	Phase	Oil: Temperature Degrees Centigrade	Oil: Power Factor	Winding Power Factor at 40 Degrees Centigrade: High+Low	High	Low
1	as found	333	13.2/4	1	0	0.2	46.8	20.8	40.5
	as left				15	New	2.94	2.07	3.98
2	as found	5,000	33/4	3	12	1.7	23.4	5.2	24.3
	as left					New	3.44	1.14	2.46
3	as found	3,333	33/13.2	1	30	0.8	30.6	12.4	23.4
	as left				27	New	3.3	0.7	2.8
4	as found	3,333	33/13.2	1	30	0.9	34.3	12.5	26.8
	as left				27	New	2.8	0+	3.1
5	as found	833	13.2/2.3	1	25	10.9	36.4	32.3	27.1
	as left				30	New	5.7	2.5	3.5
6	as found	833	13.2/2.3	1	25	11.3	39.4	33.0	30.1
	as left				30	New	4.9	1.75	3.7
7	as found	833	13.2/2.3	1	25	4.6	9.0	13.4	8.8
	as left				30	New	5.2	3.5	3.6

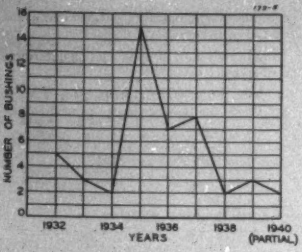

Figure 5. Bushing failures

Cause:	
Moisture	69 per cent
External	23 per cent
Impulse	6 per cent
Internal pressure	2 per cent

factory in that the investigation of all rejected equipment has disclosed faults warranting its removal from service.

6. A close inspection should be made of all seals on bushings namely, gaskets, cement, litharge, etc., for defective seals have accounted for the largest number of failures.

7. Faulty equipment should be removed from service immediately and in extreme cases, equipment held out of service until such replacement is made.

8. Reconditioning of equipment may be accomplished at a reasonable cost and at the same time provide years of useful life to equipment that might otherwise prove to be a costly emergency repair job.

9. A centralized shop, where reconditioning is being done by the power company, provides the most economic and reliable method of reconditioning insulation.

Table V. Instrument Transformers Rejected by Power Factor (1936 to 1940)

	Type P.T.	Number Rejected	Type C.T.	Number Rejected
1936	*VC*	17	*OA*	2
	P	6	*K*-32	5
	E-15	4	*K*-61	2
	E-116	8	*K*-204	1
			KE (meter unit)	2
	Total	35		12
1937	*VC*	9	*K*-32	2
	P	2		
	E-15	2		
	E-16	16		
	E-116	10		
	Total	39		2
1938	*VC*	6	*K*-204	1
	E-115	2		
	E-116	1		
	Total	9		1
1939	*E*-15	2	*K*-32	1
1940 (partial)	*VC*	2	*K*-204	1
	E-116	13		
	Total	15		1

10. Reconditioned equipment in service is showing no increase in power factor in subsequent field tests.

11. The experience gained has provided the means for a more logical consideration of new design.

12. The economics involved in this type of testing cannot be evaluated, but from the standpoint of "preventive maintenance," service continuity, and customer satisfaction, it is unquestionably justified.

Bibliography

1. Bushing P.F. Tests Show Failure Causes, E. L. Schlottere. *Electrical World*, March 28, 1936, pages 34–7.

2. Testing Bushings and Insulation by Power Factor Method, I. W. Gross and H. E. Turner. *Electrical World*, January 13, 1934, pages 68–73, and January 20, 1934, pages 111–16.

3. Portable Schering Bridge for Field Tests, C. F. Hill, T. R. Watts, and G. A. Burr. AIEE Transactions, volume 53, 1934 (January section), pages 176–82.

4. Discussions of above paper—AIEE Transactions, volume 53, 1934 (April section), pages 618–22.

5. Field Testing of Bushings and Transformer Insulation, I. W. Gross. AIEE Transactions, volume 57, 1938 (October section), pages 589–96.

6. Power Factor Testing of Transformer Insulation, Frank C. Doble and G. H. Browning. *Electrical World*, December 2, 1939, pages 49–50.

7. High Voltage Bushings Tested in Place, C. F. Benham. *Electrical World*, September 28, 1935, pages 29–30. 77.

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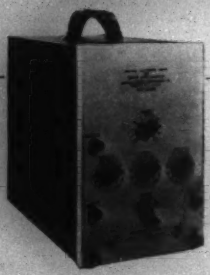

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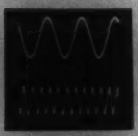
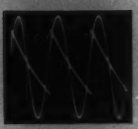


Photo showing comparison of two harmonically related signals on single oscillograph screen, using electronic switch. Patterns displaced for individual observation. Can be superimposed if preferred for very close comparison.



Independence and freedom from interaction of two channels shown in this photo. Illustrates ability of electronic switch to handle sawtooth and sinusoid at same time, and to make them appear as one oscillograph pattern.

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- Literature describing DuMont Electronic Switch and DuMont Oscillographs sent on request. Do not hesitate to submit your problems for our specialized engineering collaboration.

DUMONT

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Trade Literature

[Mailed to readers free—unless otherwise noted—upon request to companies named]

Instruments.—Catalog I-21. Describes a-c voltmeters, ammeters, galvanometers, milliammeters and other instruments for industrial, electrical and aircraft purposes. DeJur-Amsco Corporation, Shelton, Conn.

Snap-Action Switches.—Catalog, 36 pp. Comprises engineering data on precision snap-action switches and includes dimensions, prices, operating characteristics and applications. Micro Switch Corp., Freeport, Ill.

Switchgear.—Bulletin B-6012A, 24 pp. Describes metalclad, vertical-lift switchgear equipment; includes many installation views as well as dimensions, outline drawings and circuit diagrams. Allis-Chalmers Mfg. Co., Milwaukee, Wis.

Reactors.—Bulletin GEA-1090A, 4 pp. Describes oil immersed, current-limiting reactors and the advantages of this type of apparatus for protecting current-conducting equipment. General Electric Co., Schenectady, N. Y.

Miniature Bearings.—Bulletin. Describes new, self-aligning pivot bearings for radial and thrust loads. Such miniature bearings are applicable in instruments of many types. Miniature Precision Bearings, Lebanon, N. H.

Industrial Capacitors.—Catalog 164, 40 pp. Describes capacitors for motor starting and other a-c applications. Discusses capacitor characteristics as related to the requirements for various industrial uses. Cornell-Dubilier Electric Corp., South Plainfield, N. J.

Safety Switches.—Catalog 126, 76 pp. This condensed catalog contains listings and the latest prices of safety switches, service equipment, multibreakers and other circuit breakers, panelboards, motor control and pressure switches. Square D Co., 6060 Rivard St., Detroit, Mich.

Lamp Ballasts.—Catalog. Describes 62 types and sizes of lamp ballasts available for fluorescent lamp application. With the catalog is included Engineering Service No. 57, which contains technical data and information useful to prospective employers of fluorescent lighting. The Acme Electric & Mfg. Co., Cuba, N. Y.

Lightning Arresters.—Cat. Sec. 38-120, 32 pp. Describes station type auto-valve lightning arresters with ratings from 3 to 240 kv. Principles involved in the arrester functions are discussed with a note on protective ratios. An interesting map of the United States showing annual isoceraunics of total thunderstorm days, 1904-1933, is reproduced. Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.

Wiping Solder.—Bulletin. Describes a recently developed wiping solder for cable work, line splicing and other utility applications. This newly introduced, patented product is said to improve workability and to result in smoother, non-porous and uniformly sound joints. The finer grain of the new solder is illustrated and compared with standard preparations. Joseph T. Ryerson & Son, Inc., Chicago.

Strip-Chart Recorders.—Bulletin 570, 16 pp. Describes newly designed instruments used for measuring and recording on a 6-inch strip-chart: d-c amperes and milliamperes, d-c volts and millivolts, pressure, liquid level, flow, mechanical motion, and for remote recording. The Bristol Co., Waterbury, Conn.

Ventilating Fans.—Catalog X4059, 16 pp. Describes exhaust and ventilating fans for commercial, industrial and domestic installations. . . . . **Air Circulators.**—Catalog X4058, 8 pp. Describes ultra-quiet fans, each available with ceiling, wall-bracket, counter-column and adjustable floor column mountings. The Emerson Electric Mfg. Co., St. Louis, Mo.

(Continued on page 22)

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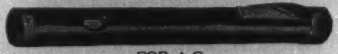

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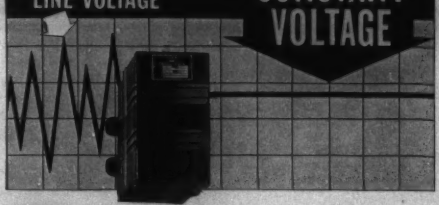

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*C8.7	Specifications for Enameled Round Copper Magnet Wire. (C8.5, 8.6 and 8.7 published as one pamphlet) (1936)	.30
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Seven such sections are now available in report form for purpose of criticism, and copies will be sent without charge upon request. These sections are as follows:

No. 6	Mercury Arc Rectifiers.	501	Test Code for D-C Machines.
21	Apparatus Bushings (3-41) (Including Test Code)		
24	Protector Tubes	40	Electrical Recording Instruments.
25	Fuses Above 600 Volts.		
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THE NIGHTMARE OF THE TWO USELESS CONVERTERS

Or, what's all this about Fiberglas* for preventive maintenance?

A MANUFACTURER of electrical products was having nightmares.

He'd dream that his two 500 K.W. rotary converters both broke down *at once*, and he'd wake up in a cold sweat, because his plant had 750 D.C. motors depending on those converters for current!

Sure, the converters had been working okay for more than 15 years. But suppose they gave up the ghost *now*? The motors would be useless!

Besides, the plant was running 24 hours a day, seven days a week on defense orders! Production would stop; plant profits would go out the window; and the cost would be enormous. No wonder the manufacturer had nightmares.

So what did he do?

To be on the safe side, this manufacturer insulated his converters, one after another, with Fiberglas Electrical Insulation . . . *to get the higher safety factor Fiberglas provides!*

And that, Sir, is the smartest kind of preventive maintenance!

Perhaps you have electrical equipment which has never been troublesome or expensive because of breakdowns. Even so, that equipment is probably running extra hours now—on defense work. The danger of downtime is there; and one of the best ways to guard against it is to insulate with Fiberglas.

For instance . . .

Rewinding your standard-size, Class A motors with Fiberglas will give you the *maximum* safety factor!

Get Fiberglas Motors

If you intend to buy new motors, specify the Fiberglas-insulated lines made by leading motor manufacturers. These motors can be supplied in smaller frames than present Class A-insulated motors of the same H.P.! Yet they operate safely at the resulting approved higher temperatures, and . . . *still have a substantially higher safety factor!* The cost is a little more in some instances—no more in others.

Case history after case history shows how remarkably Fiberglas has outlasted other insulations . . . *cutting operating costs on the toughest jobs!*

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Today, you'll find Fiberglas saving money on equipment that works under conditions of high temperature, moisture, corrosive fumes, dirt, and even many acids. That's why many of the best-known names in industry *use* Fiberglas Electrical Insulation, and consider it excellent insurance against downtime.

On your own new equipment, and on repair jobs, get the advantages of Fiberglas. Specify it! *Owens-Corning Fiberglas Corporation, Toledo, Ohio. In Canada: Fiberglas Canada, Ltd., Oshawa, Ontario.*

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We have, in our Philadelphia warehouse, a large stock of "Megger" instruments for measuring Insulation Resistance, Ground Resistance and Conductor and Contact Resistance.

Write for descriptive Catalogs 1685-EE and 1645-EE.

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1211-13 ARCH STREET *Electrical and Scientific Instruments* PHILADELPHIA PA

Trade Literature

(*Continued from p. 18*)

Drafting Standards.—Bulletin, 32 pp., "Drafting Standards—Accepted and Proposed". Contains the complete drafting standards of ASME and American Welding Society, as well as one page of proposed standards not yet accepted by ASA and not yet published elsewhere. Welding symbols are included. The book will be sent to draftsmen, designers and educators upon request on company stationery. Chas. M. Higgins & Co., Inc., 271 Ninth St., Brooklyn, N. Y.

Cable Installation Equipment.—Catalog, 24 pp. Describes conduit rods, rod adapters and pullers; cable reel jacks, feeders and drawing-in protectors, cable benders, cable racks, manhole guards, ladders and cover hooks, concrete cutters; laying, test and flexible mandrels and other conduit tools. Price list is included. T. J. Cope, Inc., 6120 Vine St., Philadelphia, Pa.

Fuse Cutouts.—Bulletin 215, 32 pp. A comprehensive outline of the principle of "Semafor Ejector" and other type cutout design and operation. Profusely illustrated and diagrammed. Method of cutout selection for any required service is described. Typical installations are shown. Schweitzer & Conrad, Inc., 4435 Ravenswood Ave., Chicago, Ill.

Distribution Transformers.—Bulletin B-6159, 16 pp. Describes new standard distribution transformers that meet all recommendations in first report of the EEI-NEMA joint committee on transformer standards. Design and construction features are covered, as well as dimensions, price lists, and electrical data for sizes of $1\frac{1}{2}$ kva to 25 kva for standard voltages of 2,400 to 13,200 inclusive. Allis-Chalmers Mfg. Co., Milwaukee, Wis.

Bushing Test Set.—Catalog E-54(4), 12 pp. Describes new portable equipment for measuring the power factor and capacitance of installed bushings, insulators and other high-voltage dielectrics. The equipment is immune to electromagnetic and electrostatic stray-fields; reads directly in terms of capacitance and power factor; and it is unnecessary to apply correction factors at the normal test voltage of 10,000 volts. Leeds & Northrup Co., 4934 Stenton Ave., Philadelphia.

Insulating Varnishes.—Bulletin, 34 pp. The purpose of this manual is to assist the user in the proper selection and application of insulating varnishes. All varnishes usually required are described in sequence based upon their relative importance, in terms of extent and variety of use, including 31 different Harvel and other insulating varnishes, paints and enamels, giving the characteristics, uses, applications, and types. Profusely illustrated with pictures, charts and useful tables. Irvington Varnish & Insulator Co., Irvington, N. J.

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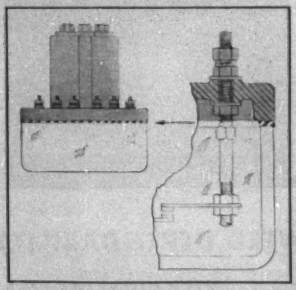
No. 2 of a Series

PROBLEM: To seal a railway signal relay housing and prevent corrosion of the silver contact points

SOLUTION: Compressible gaskets of Armstrong's Corprene DC-113

A MANUFACTURER of flasher relays, used with railway crossing signals, was troubled with corrosion of the silver contact points in his product. The top plate of his equipment was made of molded bakelite, and the main housing of molded glass. Sealing the uneven surfaces between these two materials called for a soft gasket. Rubber-like materials were tried, but these extruded badly when the flange bolts were drawn down sufficiently to effect a tight joint. In addition, the free sulphur in these compounds seriously corroded the silver contacts. Other gasket materials permitted the entrance of corrosive gases which damaged the silver points.



Corprene Goes to Work

Then Armstrong's Corprene DC-113 was tried . . . and the manufacturer's sealing problems were over! Since this material is truly compressible, no extrusion now occurs when the flanges are tightened. Since it is impervious to liquids and gases, an hermetic seal is now assured. Since it contains no free sulphur, the silver contact points now remain bright and clean.

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More than two dozen Corprene (cork-and-synthetic-rubber) compositions are available—in sheets, cut pieces, and molded parts. The physical properties of these materials can be accurately controlled to meet stringent "special case" requirements. That's why, today, Corprene is licking tough sealing problems in transformers, switches, potheads, cables, circuit breakers, and other electrical equipment. So—if you're anxious to end *your* sealing woes, write Armstrong Cork Company, Industrial Division, 943 Arch Street, Lancaster, Pennsylvania.

ARMSTRONG'S Corprene

COMPOSITIONS OF CORK AND RUBBER-LIKE MATERIALS

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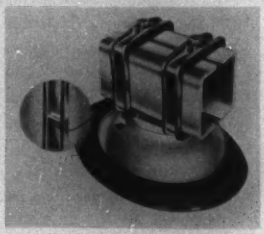
New Products

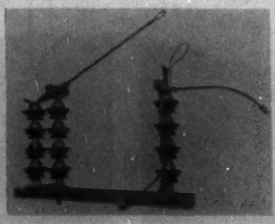
Bus Support Clamps.—The type BH bus support clamp developed by the Burndy Engineering Co., 459 East 133rd St., New York City, is shown assembled to provide a rigid support for channel bus bar. The circled inset illustrates the position of the



clamp when a slide fit on the conductor is desired. This device may be used alternatively as a slide fit support or as a rigid support by simply clamping the caps in the desired position. Center clamping studs and guide ridges insure proper spacing of the copper channels.

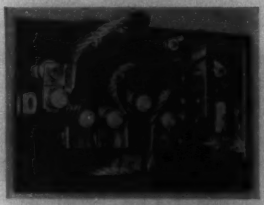
Fibre Glass Adhesive Tape.—The Industrial Tape Corporation, New Brunswick, N. J., has developed a fibre glass adhesive tape with a pressure sensitive coating. The new product is expected to find many applications in the electrical industry, and for insulating other than electrically. The tape is manufactured in rolls in the full width of 40 inches and then cut into any desired widths, exactly as paper-backed and cloth-backed tapes are cut.

Balanced Blade Switch.—The illustration shows a single pole element of an improved type high pressure contact 3-pole switch, equipped with grounding blade and wire guides, introduced by the Delta-Star Electric Co., 2400 Block, Fulton St., Chicago, Ill. The main blade is shown in partially open position, particularly to illustrate its full control and balancing in all positions. The main blade has high pressure contacts at both ends. No flexible braids are used and as the back-up springs carry no current they cannot anneal or lose resilience. Rating is 161 kv, 600 amperes, main and grounding blade.



Oil Insulated Magnetic Contactor.—The development of a line of magnetic contactors, insulated with transformer oil, for use on circuits carrying as high as 5,000 volts and as high as 15 amperes, has been announced by Peerless Laboratories, Inc., New York City. The unit is enclosed in a housing 7 by 8 by 4 inches, and is available up to two normally closed circuits and two normally open circuits. The magnet coil may be operated on either 120 or 220 volts, a-c or d-c, and draws less than 10 watts, thereby making it suitable for use on tube circuits. The standard unit is intended for stationary service. For mobile applications it can be supplied completely sealed and furnished with expansion bellows. According to the manufacturer, the unit is applicable wherever high voltage remote control switching and compactness are important factors.

Relay.—A 4-pole, double throw relay is the newest addition to the line of type "C" relays manufactured by the G-M Laboratories, of Chicago. One of its outstanding features is precise machine assembly of parts, which makes for economical quantity production. Operating voltages under

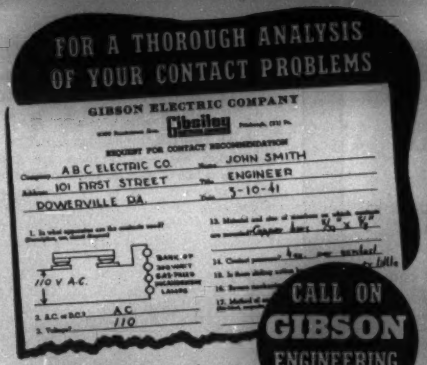


normal conditions range from 2 to 230 volts a-c and 2 to 125 volts d-c. Normal contact capacity is 10 amperes on non-inductive a-c loads, but special contact materials for specific applications may permit the control of considerably higher current.

Dry Developer Paper Free for Test.—To owners of ammonia vapor machines who care to cooperate in the "field trial" test under working conditions, The Frederick Post Co., P.O. Box 803, Chicago, is delivering a stock of "VAPOpaper" without charge, asking only a brief report on its performance in return. Owners of these dry developer machines may secure a trial stock of the new paper by sending the model or serial number of their machines to the paper manufacturer. Among the improvements claimed for the new paper are: 50% rag content bond against sulphite stock used in existing papers; two "speeds" in sensitivity—regular and fast; two colors—blue and red. The new sensitizing medium is said to print out to a cleaner, whiter background and at the same time leaves all lines in deeply colored contrast.

(*Continued on page 28*)

FOR A THOROUGH ANALYSIS OF YOUR CONTACT PROBLEMS



Modern electrical control equipment imposes severe duties on contacts, which must carry heavy currents without overheating, maintain low resistivity, and open or close high instantaneous currents without burning or welding. To achieve these results under various conditions of current, voltage, inductance, frequency of operation and contact pressure, requires material possessing a wide variety of characteristics. GIBSILOY, produced by powder metallurgy, is made in numerous grades to meet these various and exacting requirements.

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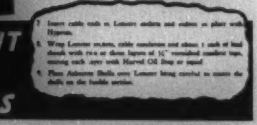

In the Burndy Engineering Catalog on Mole Line Equipment for Underground Net Work Systems, OIL STOP is mentioned on page 13 for use with installations of Burndy Limiters on Oil Impregnated Paper Insulated Cable.

OIL STOP is a phenol-aldehyde synthetic resin which has many uses in the electrical industry for cable splicing, low cost oil tight terminals, stop joints, insulating buses, cementing transformer gaskets, repairing cracked bushings, coil sealing, waterproof coatings, etc.

OIL STOP has the following qualities: completely seals against any kind of oil or water; easily applied as a liquid, yet polymerizes at ordinary temperatures into a firm enduring, infusible insulation—whether exposed to air or not; forms no vapor pockets during polymerization—being free of solvents; will not melt or soften after setting; resists vibration; has excellent adherence to rubber, oil-impregnated paper, molded plastics and fibre; has good adhesion to copper; and is not affected by acid or alkali solutions.

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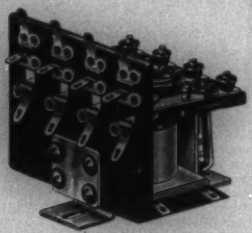
New Products

(Continued from p. 24)

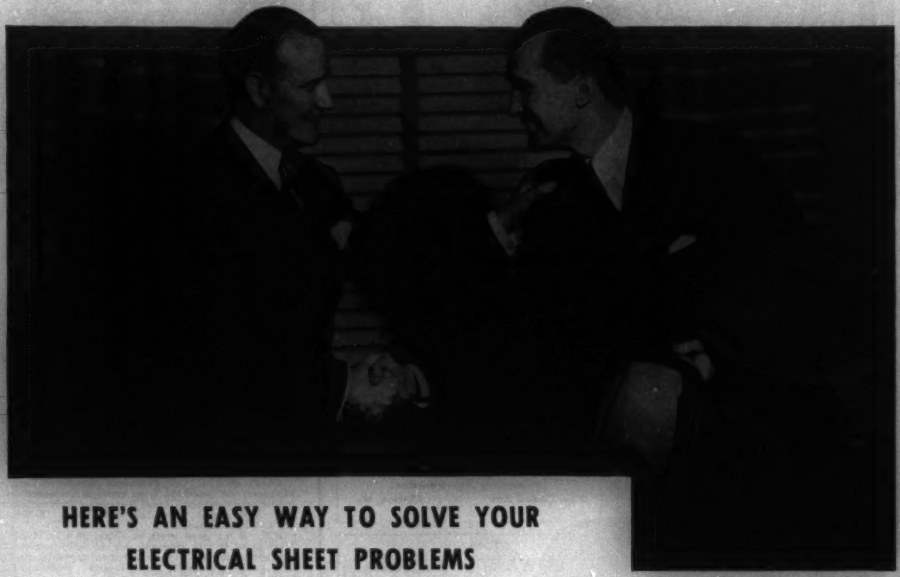
Electrical Contacts.—Gibsiloy grade "A" silver-nickel electrical contacts are employed in a line of aircraft battery transfer switches recently built by the Automatic Switch Co., New York, N. Y. These contacts are required to handle 200 amperes at 24 volts d-c, and were chosen for this



application because fine silver contacts would roughen under the severe operating conditions, whereas Gibsiloy retains a smooth, unpitted contact surface. Such contacts approach silver in conductivity, and their high resistance to wear and pitting assures low contact resistance—consequently, low operating temperatures. Gibsiloy grade "A" silver-nickel is one of several ductile contact materials made from powdered metals by the Gibson Electric Co., 8348 Frankstown Ave., Pittsburgh, Pa.

New Cam-Operated Controller.—Speed-up production, through reduced fatigue, is claimed for the new line of cam-operated, mill duty controllers developed by Cutler-Hammer, Inc., Milwaukee, Wis. Extreme ease of operation with positive feel of all speed positions is obtained by using an adjustable compression type of star wheel spring. Available in two-speed, three-speed, and multi-speed types, the controllers are suitable for mill auxiliaries, crane hoist, bridge, and trolley applications. Contacts are vertical, double break, silver-to-silver; the cam shaft operates on sealed ball bearings. An easily accessible terminal board simplifies installation and service, and a heavy cast case and cover, for either separate or benchboard mounting, provide protection from dust and mechanical injury. Optional features include: spring return, off-position latch, two, three or five speeds.

"Thanks again for helping us out"



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"I judge the telephone company by the people who work for it"

A little while ago a Vermont newspaper editor, John Hooper, commented on the telephone company and its people. His words express so well the ideals toward which we are striving that we quote them here.

"I DON'T know how big the telephone company is, but it is big enough to exceed my mental grasp of business.

"But I don't find myself thinking of it as a business, even in my day-to-day contacts. Rather, my attention is on the voice that says, 'Number, please.' I find myself wondering if that voice is feeling as well as it always seems to, or if it feels just as hot and weary as I do, and would say so if it wasn't the kind of voice it is.

"The first time the business angle really struck home was when I read that my friend Carl had completed thirty years with the company.

"Now it happens that I know something of the details of those thirty years with the company, and I believe they are a credit both to Carl and to the big business for which he works.

"In 1907 Carl was a high school boy confronted with the need for earning money in his spare time. He happened to get a job as Saturday night operator in the telephone exchange. He worked at this job for three years and then entered the university.

"While in college he did some substituting at the exchange in his home town in vacations. After graduation, he was hired full time by the telephone company, not in an 'executive' position which some folks think goes with a college diploma, but as a lineman.

"Within a year he was made wire chief of the district, a job which he held for the next ten years. He was then transferred to a larger city as manager of the office. Then he was promoted to sales manager of the division.

"A year later he was sent to another State, as district manager. In less than a year after this appointment, he was made manager for the entire State.

"I don't know much about the telephone company as a business; I can only judge it by the people who work for it. Just where the dividing line is between a business and the people who work for it, I don't know. I don't think there is any line."

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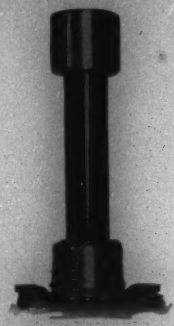

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Electrical Installations on Shipboard

(MARINE RULES)

Sec. No. 45 AIEE Standards With Addenda as of March 1941

THE latest edition "of Recommended Practise for Electrical Installations on Shipboard" (Marine Rules) is published as Section 45 of the AIEE Standards. The pamphlet contains 100 pages; price is $1.50 (50% discount to members of the AIEE).

These rules have been drawn up to serve as a guide for the equipment of merchant ships with electrical apparatus for lighting, signaling, communication, power and propulsion for both alternating and direct current systems. They indicate what is considered good engineering practise with reference to safety of the personnel and of the ship itself, as well as reliability and durability of the electrical apparatus.

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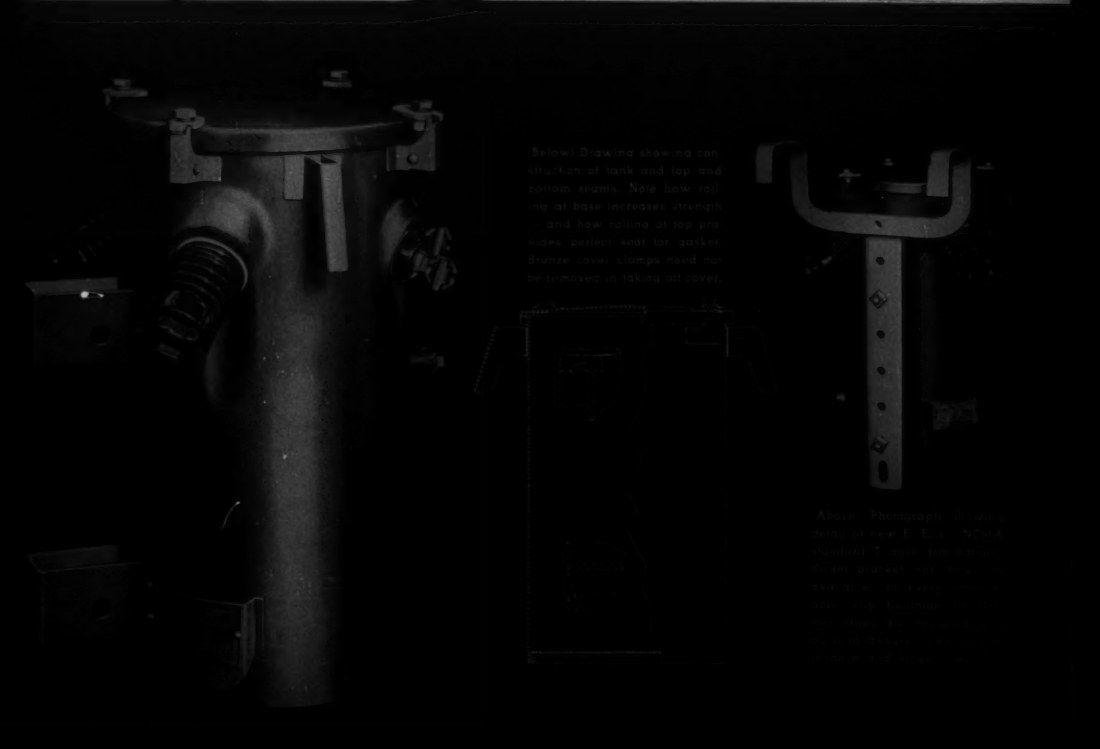

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